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# A new approach to modeling aviation accidents

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# A NEW APPROACH TO MODELING AVIATION ACCIDENTS

by

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*To Amma and Papa*

*"You are the reason I am; you are all my reasons"*

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# ABSTRACT

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General Aviation (GA) is a catchall term for all aircraft operations in the US that are not categorized as commercial operations or military flights. GA aircraft account for almost 97% of the US civil aviation fleet. Unfortunately, GA flights have a much higher fatal accident rate than commercial operations. Recent estimates by the Federal Aviation Administration (FAA) showed that the GA fatal accident rate has remained relatively unchanged between 2010 and 2015, with 1566 fatal accidents accounting for 2650 fatalities. Several research efforts have been directed towards betters understanding the causes of GA accidents. Many of these efforts use National Transportation Safety Board (NTSB) accident reports and data. Unfortunately, while these studies easily identify the top types of accidents (e.g., inflight loss of control (LOC)), they usually cannot identify why these accidents are happening. Most NTSB narrative reports for GA accidents are very short (many are only one paragraph long), and do not contain much information on the causes (likely because the causes were not fully identified). NTSB investigators also code each accident using an event-based coding system, which should facilitate identification of patterns and trends in causation, given the high number of GA accidents each year. However, this system is susceptible to investigator interpretation and error, meaning that two investigators may code the same accident differently, or omit applicable codes.

To facilitate a potentially better understanding of GA accident causation, this research develops a state-based approach to check for logical gaps or omissions in NTSB accident records, and potentially fills-in the omissions.

The state-based approach offers more flexibility as it moves away from the conventional event-based representation of accidents, which classifies events in accidents into several categories such as causes, contributing factors, findings, occurrences, and phase of flight. The method views aviation accidents as a set of hazardous states of a system (pilot and aircraft), and triggers that cause the system to move between hazardous states. I used the NTSB's accident coding manual (that contains nearly 4000 different codes) to develop a "dictionary" of hazardous states, triggers, and information codes. Then, I created the "grammar", or a set of rules, that: (1) orders the hazardous states in each accident; and, (2) links the hazardous states using the appropriate triggers. This approach: (1) provides a more correct count of the causes for accidents in the NTSB database; and, (2) checks for gaps or omissions in NTSB accident data, and fills in some of these gaps using logic-based rules. These rules also help identify and count causes for accidents that were not discernable from previous analyses of historical accident data.

I apply the model to 6200 helicopter accidents that occurred in the US between 1982 and 2015. First, I identify the states and triggers that are most likely to be associated with fatal and non-fatal accidents. The results suggest that non-fatal accidents, which account for approximately 84% of the accidents, provide valuable opportunities to learn about the causes for accidents.

Next, I investigate the causes of inflight loss of control using both a conventional approach and using the state-based approach. The conventional analysis provides little insight into the causal mechanism for LOC. For instance, the top cause of LOC is “aircraft control/directional control not maintained”, which does not provide any insight. In contrast, the state-based analysis showed that pilots’ tendency to clip objects frequently triggered LOC (16.7% of LOC accidents)—this finding was not directly discernable from conventional analyses.

Finally, I investigate the causes for improper autorotations using both a conventional approach and the state-based approach. The conventional approach uses modifiers (e.g., “improper”, “misjudged”) associated with “24520: Autorotation” to identify improper autorotations in the pre-2008 system. In the psot-2008 system, the NTSB represents autorotation as a phase of flight, which has no modifier—making it impossible to determine if the autorotation was unsuccessful. In contrast, the state-based analysis identified 632 improper autorotation accidents, compared to 174 with a conventional analysis. Results from the state-based analysis show that not maintaining rotor RPM and improper flare were among the top reasons for improper autorotations. The presence of the “not possible” trigger in 11.6% of improper autorotations, suggests that it was impossible to make an autorotative landing. Improper use of collective is the sixth most frequent trigger for improper autorotation. Correct use of collective pitch control is crucial to maintain rotor RPM during an autorotation (considering that engines are generally not operational during autorotations).

# CHAPTER 1. INTRODUCTION

*"The idea of a vehicle that could lift itself vertically from the ground and hover motionless in the air was probably born at the same time that man first dreamed of flying."*

–Igor Ivanovitch Sikorsky

The Greek words *helix* (for spiral) and *pteron* (for wing) led to the genesis of the French term *hélicoptère* meaning “device for enabling airplanes to rise perpendicularly”. Helicopters have demonstrated their operational versatility by their ability to execute vertical takeoffs and landings (VTOL), and hovering capability. In addition to military operations, helicopters have found application in multiple civilian missions including Emergency Medical Services (EMS), search and rescue, transport to off-shore locations, external load operations, law enforcement, and aerial application (including firefighting) missions. Since helicopter missions can often be time-critical and involve flights in proximity to terrain/objects, they impose demanding requirements on both crew and machine.

Analysis of General Aviation (GA) accident data by several researchers and safety teams generally arrive at a common conclusion—*Inflight loss of control (LOC) is the top cause for GA accidents*. Harris et al. (2000) analyzed over 8000 helicopter accidents that occurred during 1963–1997. They found that LOC was the cause for 625 out of 5371 (approximately 12%) accidents involving civilian helicopters. In 2010, the US Joint Helicopter Safety and Analysis Team (US JHSAT) selected and analyzed 523 helicopter accidents for 2000, 2001, and 2006 (they do not specify the reasons for selecting the aforementioned years for their analysis). In their analysis, they found that inflight loss of control was the top cause—

accounting for over 41% of the accident in their dataset (US JHSAT, 2011). In a related study, the US Joint Helicopter Implementation Measurement Data Analysis Team (US JHIMDAT) analyzed 415 helicopter accidents that occurred between 2009 and 2011 (US JHIMDAT, 2014). Their analysis showed that inflight loss of control was not only the top cause, but accounted for greater proportion of accidents when compared to the US JHSAT study (47.5% compared to 41%). A 2012 study by the Government Accountability Office (GAO) to improve GA safety termed LOC as the most frequent "defining event" in GA accidents. In fact, recently, we (Rao and Marais, 2015) analyzed 5051 helicopter accidents that occurred in the US in 1982–2008[1], and identified LOC as the most frequent single-node occurrence chain.

While all of these studies indicated that LOC was the top reason for GA (fixed wing and helicopter) accidents, they did not provide any information on "why" the accident-aircraft (and pilot) experienced loss of control.

Despite the best efforts of airframe manufacturers, safety teams, and regulatory authorities, helicopter (and more generally fixed wing General Aviation (GA)) accidents continue to occur, often resulting in severe injury and damage consequences. The relatively high frequency of GA accidents (compared to commercial operation accidents) suggests that we (the safety community) have a limited understanding of the causes for GA accidents—raising the question:

*Why are we not learning as much as possible from GA accidents?*

[1] The NTSB established the accident database in 1962. The database underwent a major recording overhaul in 1982 and another change in 2008. This thesis uses data from accidents that were recorded after 1982.

There could be multiple potential answers to this question. One of the reasons could be that the nature of GA accident investigations and reporting potentially limits our understanding of accident causation. A combination of the high frequency of GA accidents and limited investigative resources results in GA accident reports not having the same depth of information when compared to commercial (Part 121) accidents. Another reason for our limited understanding of GA accident causation could be due to the tendency to analyze limited datasets (e.g., specific injury severity, helicopter model) and draw conclusions from them. In many cases, subject matter experts use the results from these analyses to propose specific intervention strategies and safety enhancements. While these measures address specific safety concerns (e.g., developing fire-resistant fuel tanks to prevent post-crash fires), they do not help us better understand accident causation in a large set of accidents. A third possible reason for the limited understanding of GA causation could be due to the setup of the NTSB accident coding system.

In this research, I focus on developing a new approach to modeling aviation accidents. This thesis aims to steer the accident analysis community towards a path to potentially better understanding accident causation. Our pursuit of reducing the number of accidents raises the following question:

> *The NTSB database contains a wealth of data, but is not always logically complete and omissions—can we develop an approach that enables logical checking and potentially removes the omissions?*

This thesis revolves around using historical accident data to better understand aviation accident causation in general. I use a state-based approach to modeling aviation accidents, and illustrate this new approach by using historical helicopter accident data. The remainder of this chapter is laid out as follows: I begin by giving the reader some relevant background on GA and helicopter safety (Sections 1.1 and 1.2). Then, I lay out the research goals and provide an outline of the thesis in Sections 1.3 and 1.4, respectively.

## 1.1 What is General Aviation (GA)?

General Aviation (GA) is a catch-all term for all aircraft operations in the US that are not categorized as commercial operations or military flight (Shetty and Hansman, 2012). The International Civil Aviation Organization (ICAO) defines GA operations as "*as all civil aviation operations other than scheduled air services and non-scheduled air transport operations for remuneration or hire*" (ICAO, 2009). In 2014, GA aircraft comprised approximately 97% of the US civil aviation fleet (Fala and Marais, 2016).

In its most recent *General Aviation and Part 135 Survey*, the FAA (2014) estimated that there were 204,408 aircraft in the GA fleet—78.9% were fixed-wing aircraft, while 4.9% were rotorcraft. The FAA classified 12.8% of the fleet as *experimental* aircraft and the remaining 3.4% in the *other* (gliders and lighter-than-air) aircraft category. The GA fleet is composed of aircraft ranging from homebuilt aircraft that generally use steam gauges (e.g., Piper Cub) to state-of-the-art aircraft (e.g., Gulfstream G650) with modern avionics and on-board Flight Data Recorders (FDRs).

GA operations cover a broad variety of aviation activities that include emergency air medical services, student pilot instructional activities, and personal use flights. Generally, these operations can be categorized as either local or itinerant (Shetty and Hansman, 2012). The FAA defines local operations as "*those operations performed by aircraft that remain in the local traffic pattern, execute simulated instrument approaches or low passes at the* *airport, and the operations to or from the airport and a designated practice area within a 20−mile radius of the tower*" (FAA, 2016a). Operations that involve personal flight, instructional activities, or aerial observation missions could be classified as local operations, while corporate or business flights are classified as itinerant operations (Shetty and Hansman, 2012).

Table 1: Breakdown of Active GA Aircraft Based on Primary Use (FAA, 2014)

| **Type of Operation** | **Proportion of Total GA Aircraft** |
|---|---|
| Personal use | 66.4 |
| Business | 7.7 |
| Instructional | 6.4 |
| Corporate | 5.8 |
| Remaining operations (<5% each)[2] | 13.7 |
| Total | 100.0 |

In its General Aviation and Part 135 survey, the FAA categorizes GA operations into 15 different operation types. I grouped the 11 operation types that individually accounted for less than 5% of the total active GA aircraft, and placed them under *Remaining Operations*, as shown in Table 1. These operations included *air taxi* (3.4%), *aerial observation* (2.9%), and *aerial application* (1.5%). The *personal use* category accounted for more than two-thirds (66.4%) of all active GA aircraft in 2014. Personal use operations typically involve flights by aviation enthusiasts and hobby flyers. Many GA flights involve student pilots operating aircraft with (or without) the supervision of certified flight instructors (CFIs). In 2014, the FAA estimated that 6.4% of GA aircraft were used for instructional flights.

[2] Each of the remaining 11 categories accounted for less than 2% of the total active GA aircraft. Some of the remaining categories include air taxi (3.4%), aerial observation (2.9%), other (2.4%), and aerial application (1.5%),

## 1.2 Vertical Flight Safety: Background and Motivation

In the latter part of the 19th Century, the modern-day term "helicopter" was born. Historical literature shows (Figure 1) that efforts to build a powered lift system were well underway before the conception of the fixed-wing airplane (Harris, 2012).

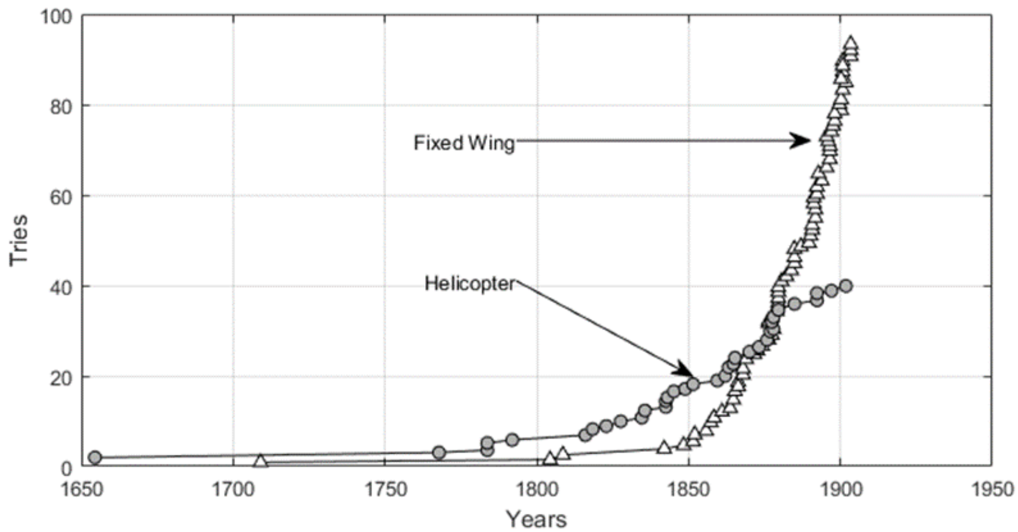


Figure 1: Timeline showing early efforts by inventors to build helicopters [adapted from Harris (2012)].

Between 1900 and 1939, several inventors and vertical flight enthusiasts experimented with different designs with limited success. The 1930s saw the first steps towards the development of the modern helicopter. In May 1940, the US Army Air Corps successfully test flew Sikorsky's VS-300 helicopter. In the years that followed, the Vought-Sikorsky company designed helicopters such as the XR-4, which had a gross weight of 2700 lb. and cruised at an altitude of 5000 ft.—capturing the attention of the US Navy. Then, with the development of the R-4, the Department of the Interior recognized the potential of using helicopters in forest and wildlife management.

While initial development and designs were tailored for military purposes, the work of a few vertical flight pioneers resulted in the introduction of helicopters in the commercial sector. Arthur Young and Lawrence “Larry” Bell’s persistence led to the design of Bell Ship-1. The Bell 47, which was a derivative of the Bell Ship-1 became the first civilian certified helicopter in the US. Other noteworthy individuals include Charles Kaman, and Stanley Hiller, Jr.

As the years progressed helicopters were used in a variety of missions including coastguard search and rescue, aerial application (e.g., crop dusting), law enforcement, air-taxi operations, and personal use. With increased use of helicopters came safety issues. Initially, loss of engine power, mechanical failure of on-board systems/components, and the absence of crash-resistant safety features were among the top reasons for helicopter accidents and injuries. However, the so called *fly-fix-fly* approach to helicopter safety has helped reduce the accident rate. Advancements in helicopter design, improvements in engine technology through the introduction of the turbine engine (which is considered more reliable than the piston engine), and higher standards for certification are some of the reasons that have helped reduce the number of accidents related to mechanical failures.

In recent years, regulators and safety analysts have shifted their attention to better understanding the role of the pilots/crew and organizational influences in helicopter accidents. In their annually-published “Most Wanted List”, the National Transportation Safety Board (NTSB) called for improvements in helicopter safety in two successive years (2014 and 2015). Recently, the NTSB also expressed their concern over the increasing number of loss of control (LOC) accidents in General Aviation (GA) operations[3]. They highlighted the key role of pilots, operators, and ground crews in improving safety by implementing sound risk management practices.

A large body of literature is dedicated to analyzing historical accident data to improve helicopter/GA safety. Many studies have considered helicopter risk arising from various sources such as pilot behavior, mechanical systems, mission types, times of operations (e.g., Manwaring et al., 1998; DeVoogt, et al., 2009; Dempsey et al., 2007; Atkinson & Irving, 1995).

Generally, historical helicopter accident analyses use limited data sets and rely on expert knowledge to identify key safety concerns. These studies restrict their analyses to specific injury severity levels (e.g., fatal accidents), mission types (e.g., emergency medical service flights), modes of mechanical failure (e.g., fatigue failure), or specific airframe manufacturers (e.g., Augusta Westland or Robinson). Some studies analyze the role of the operator and machine independently. Both Rasmussen (1997) and Leveson (2004) argue that to better understand accident causation, we (safety analysts) should focus on the mechanisms or factors that influence human action, and not fixate on the role of the human in accidents.

Many safety working groups have focused exclusively on the causes for fatal accidents in fixed-wing General Aviation (GA) aircraft and helicopters. In 1997, the Helicopter Accident Analysis Team (HAAT) was tasked by the Safe All-Weather Flight for Rotorcraft

[3] The NTSB's 2015 and 2016 "Most Wanted List" call for strategies to reduce the number of Loss of Control (LOC) accidents in GA operations.

(SAFOR) program with establishing the chain of events that led to fatal accidents and to propose interventions that might have eliminated one or more links, thus preventing the accident (HAAT, 1998). They chose 34 fatal rotorcraft accidents that occurred between 1989 and 1996, and found that poor pilot judgment was responsible (in part) for 50% of the accidents in their sample. Violation of flight procedure by pilots (41.2%) and inadequate or misdirected management oversight resulting in risk-taking by pilots (38.2%) were the other top problems. To reduce the number of fatal accidents, the FAA (2016) initiated a Rotorcraft Safety Initiative (RSI) in 2013. The goal of this initiative was to identify the causes for a set of fatal helicopter accidents, and come up with intervention strategies that could prevent "similar" fatal accidents. While the efforts of these groups might have helped reduce the fatal helicopter accident rate per 100,000 flight hours[4], there continue to be fatalities—reaching a 20-year high in 2013 (44 deaths).

Historical accident analysis techniques, in general, have sought to determine the "root cause" for an accident (Taylor and Adams, 1986), or establish the chain of events that preceded an accident. Some research explores the role of these events or *occurrences*[5] in aviation accidents. Most of this research considers fixed-wing aircraft, or does not explicitly highlight the role of occurrence chains (or sequences of occurrences) in helicopter accidents (Houston et al., 2012). In an effort to better understand the proximate causes for helicopter accidents, I explored the different chains of occurrences and ranked them based on different risk perspectives (e.g., injury severity, mission types). Chapter 3

[4] Fatal accident rate reduced from 1.43 in 2001 to 0.67 in 2014—a 53.2% reduction.

[5] The NTSB defines as an occurrence as "A distinct major event of relative significance that leads to an accident or incident."

of this thesis presents details of this approach and the lessons learned (see also Rao and Marais (2015)).

Historical accident analysis is dependent on the data reported by accident investigators. The value of the lessons learned from historical accident analysis is limited by the level of detail in accident reports. Generally, investigators collect data on accidents through witness/survivor interviews and examining other evidence. Assuming that all accident investigations receive the same amount of resources (manpower and time), accident reports could be a potentially rich source of information. Unfortunately, in the US, the high frequency of GA accidents and the lack of flight data recorders ("black boxes") makes it infeasible to obtain detailed information on the causes for each accident. In many cases, investigators do not travel to an accident site (colloquially referred to as a "desk top" audit), but make a determination of the probable cause based on the data available. Some of these accident reports are characterized by limited information that focuses on proximal events, and tend to leave out less obvious contributing factors that could have yielded valuable insight into the accident.

## 1.3 Research Goals and Thesis Outline

Despite many years of retrospective accident analysis, helicopter (and fixed wing GA) accidents continue to occur frequently, often resulting in fatalities and damage to property. One possible reason is that we (the accident analysis community) are limiting the lessons learned from historical data for a variety of reasons I outlined in Section 1.2.

This thesis aims to address the following gap:

*The NTSB database contains a wealth of data, but is not always logically complete and omissions—can we develop an approach that enables logical checking and potentially removes the omissions?*

To address this gap, this thesis presents a multi-year analysis of historical accident data to better understand aviation accident causation in general, specifically helicopter accidents. The fundamental question can be broken down into two research questions:

1. The current accident coding system limits our understanding of accident causation—can a different approach help?

2. Can we provide a more correct count and hence a more accurate ranking of the causes for accidents in the NTSB database?

To answer the above questions, this thesis develops an approach to model aviation accidents using a state-based approach. I use aviation accident data from the NTSB database to build a state-based accident model. Then, I use this model to potentially better understand accident causation.

Chapter 1 provides the reader with the requisite background in fixed wing GA and helicopter safety. Chapter 2 is divided into two parts. The first part reviews literature on helicopter safety, with particular emphasis on previous work in historical accident analysis. The second part of Chapter 2 provides background on commonly-used aviation accident modeling techniques. It reviews the techniques and summarizes their strengths and shortcomings.

The first half of Chapter 3 serves as a “beginners’ guide to the NTSB aviation accident database”. This chapter is motivated by the fact that I, in my years researching the database, have not found a user-friendly guide for any first-time database user. It lays out the NTSB’s accident coding systems and also highlights some key issues with the data. The second half of Chapter 3 identifies sequences of occurrence or occurrence chains that most frequently ended in accidents. It presents some of the key conclusions and highlights the shortcomings of the chain of events approach—motivating the need for a better representation of historical accident data.

Chapter 4 presents a state-based aviation accident model. I begin the chapter by providing definitions for the basic elements of a state-based approach. Then, I build the state-based model by creating a dictionary of hazardous states and triggers. After creating the dictionary, I provide the grammar that links hazardous states and triggers.

In Chapter 5, I use three examples to demonstrate the application and investigate the potential usefulness of the state-based model. I do one high-level analysis of the 6200 accidents in the database to identify the most frequent states and triggers—i.e., the states and triggers that are most likely to be associated with, or lead to, accidents. Next, I investigate the causal patterns associated with two of the most hazardous states—loss of control and improper autorotation.

Chapter 6 summarizes the contributions of this research and provides recommendations for future work.

## 1.4 Terminology

This section defines the various terms that will be referred to in this thesis.

**Accident:** An occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death, or serious injury, or in which the aircraft receives substantial damage.

**Incident:** An occurrence other than an accident, associated with the operation of aircraft, which affects or could affect the safety of operations.

**Occurrence:** A distinct major event of relative significance that leads to an accident or incident.

**Safety:** Freedom from accident or losses.

**Hazard:** A state or set of conditions of a system that, together with other conditions in the system's environment, will lead inevitably to an accident.

**Risk:** The future impact of a hazard that is not controlled or eliminated. It can be viewed as future uncertainty created by the hazard. It can also be defined as the likelihood and consequences of an accident occurring in a system.

**Risk Assessment:** The process of determining the likelihood and consequences associated with a risk.

**Risk Management:** The process that ensures that the risk is maintained at an acceptable level during the lifetime of a system.

**Exceedance:** A deviation in a flight parameter beyond an established bound/limit (upper or lower), which can result in an accident.

**Safety Event:** One or more exceedances that take place concurrently along with parameters during a specified phase of flight and directly relate to a safety of flight condition.

**Fatal Injury:** Any injury that results in death within 30 days of the accident.

**Serious Injury:** An injury that (1) requires hospitalization for more than 48 hours, commencing within seven days from the date the injury was received; (2) results in a fracture of any bone (except simple fracture of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, muscle, or tendon damage; (4) involves injury to any internal organ; or (5) involves second- or third-degree burns, or any burns affecting more than 5% of the body surface.

**Minor Injury:** If an injury does not meet the criteria for fatal or serious, select minor.

# CHAPTER 2. LITERATURE REVIEW

This chapter reviews the literature on helicopter safety and highlights key accident modeling techniques. Through this chapter, I intend to provide the reader with essential background on various efforts to improve helicopter safety, and some highlights from different approaches to modeling accidents.

The primary emphasis of the review is on studies that have used historical accident data. Sections 2.2–2.4 review various accident modeling techniques that have been used to understand the causes for aviation accidents. Section 2.5 captures the key elements of the models reviewed in and summarizes their merits and shortcomings.

## 2.1 A Review of GA and Helicopter Safety Literature

A large body of research has been dedicated to improving helicopter safety through historical analysis of helicopter accidents. Several studies have considered helicopter risk arising from various sources such as pilot behavior, mechanical systems, mission types, and times of operations (e.g., Manwaring et al., 1998; DeVoogt, et al., 2009; Dempsey et al., 2007; Atkinson and Irving, 1995). Some of their recommendations to improve helicopter safety include better crew resource management, enhanced pilot training, fuel management, and frequent maintenance to ensure healthy operating components.

Some research has explored the role of occurrences in aviation accidents. Most of this research considers fixed-wing aircraft, or specific events or causes in accidents (Houston et al., 2012). The US Joint Helicopter Safety and Analysis Team (US JHSAT) selected and analyzed 523 helicopter accidents for 2000, 2001, and 2006 (they do not specify the reasons for selecting the aforementioned years for their analysis). They found that loss of control (41% of the accidents), autorotations during practice and emergency (28% of the accidents), and system component failure (28% of the accidents), were the top three occurrences in helicopter accidents in these years (US JHSAT, 2011).

Similar to the US JHSAT's methodology, the US Joint Helicopter Implementation Measurement Data Analysis Team (US JHIMDAT) analyzed 415 helicopter accidents that occurred between 2009 and 2011 (US JHIMDAT, 2014). They carried out a "high-level" statistical analysis on the selected accidents to identify differences from the US JHSAT analysis (again, they do not mention the reasons for focusing on 2009–2011). Compared to the US JHSAT results, they noted a relative increase in the proportion of loss of control (LOC) (47.5% compared to 41.5% in US JHSAT study) and controlled flight into terrain (CFIT) accidents (6.7% compared to 3.1%), while accidents associated with system component failure decreased.

Some researchers analyzed accident data to identify initiating events (or first events) in accident chains, while other focused on "breaking" the chain of events. Harris et al. (2012) reviewed over 8000 US helicopter accidents from 1963 to 1997. They categorized the accidents based on the 21 first-event categories used by the NTSB, and identified loss of engine power, inflight collision with object, and loss of control as the top-three first-events. In 1997, the Helicopter Accident Analysis Team (HAAT) was tasked by the Safe All-Weather Flight for Rotorcraft (SAFOR) program with establishing the chains of events that led to fatal accidents and to propose interventions that might have eliminated one or more links, thus preventing the accident (HAAT, 1998). They chose 34 fatal rotorcraft accidents that occurred between 1989 and 1996 and that covered a diverse range of missions and equipment. Further, their report states that the sample was not representative of all (nor fatal) rotorcraft accidents in 1989–1996. After selecting their sample, they proceeded to identify “problems” (e.g., preflight planning, safety culture, or pilot training) that contributed to the accidents. Not surprisingly, they found that poor pilot judgment was responsible (in part) for 50% of the accidents in their sample. Violation of flight procedure by pilots (41.2%) and inadequate or misdirected management oversight resulting in risk-taking by pilots (38.2%) were the other top problems.

Several studies have focused on the causes for fatal accidents in fixed-wing General Aviation (GA) aircraft and helicopters (e.g., Conroy et al., 1992; ATSB, 2004; Li et al., 2008; Baker et al., 2011; Bazargan and Guzhva, 2007). A study by the Australian Transportation Safety Board (ATSB) looked at 215 fatal Australian GA accidents between 1991 and 2000—24.2% of which involved helicopters (ATSB, 2004). These accidents were generally caused by engine failure, incorrect control inputs by pilots, and low-level flight in proximity to objects (e.g., power lines). Li et al. (2008) developed a Fatality Index in Aviation (FIA) score to predict fatality risk in aviation crashes. They analyzed 44,628 accidents, of which 7889 (18%) involved pilot fatalities. In an effort to improve the EMS safety record, Baker et al. (2011) focused their attention on 182 fatal EMS accidents in 1983–2005. Crashes during the dark accounted for 56% of the accidents, while 77% of fatal EMS crashes happened during instrument meteorological conditions (IMC). They recommended improved crashworthiness and reduced operations during hazardous conditions to reduce fatalities.

O’Hare et al. (2006) analyzed 190 rotorcraft accidents that occurred in New Zealand in 1988–1994 to identify risk factors in fatal and serious-injury accidents. They reported post-crash fire and nature of terrain as the biggest risk factors in fatal accidents, while pilots' failure to obtain weather briefings prior to flights was an important factor in serious-injury accidents. They added that the nature of operations (e.g., short-haul flights) and the volatile New Zealand weather might have exacerbated the risk associated with not getting a preflight weather briefing. Safety organizations and regulators have also made efforts to reduce the fatal helicopter accident rate. The Helicopter Accident Analysis Team (HAAT) chose 34 fatal rotorcraft accidents that occurred between 1989 and 1996, and found that poor pilot judgment was responsible (in part) for 50% of the accidents in their sample. Violation of flight procedure by pilots (41.2%) and inadequate or misdirected management oversight resulting in risk-taking by pilots (38.2%) were the other top problems. In 2013 there were 37 fatal helicopter accidents (out of 161 total accidents)—the highest number of fatal accidents in a calendar year since 1994. In response to the high number of fatal helicopter accidents, the Federal Aviation Administration (FAA) started a Rotorcraft Safety Initiative (RSI). This initiative focused efforts only on fatal helicopter accidents. Their goal was to identify intervention strategies that could prevent "similar" fatal accidents.

Aviation maintenance tasks are complex undertakings in which individuals perform varied tasks in an environment with time constraints, minimal feedback, and sometimes difficult ambient conditions (ICAO, 1999). Several researchers have carried out historical analyses of fixed wing accidents in the GA and commercial sectors (e.g., Marais and Robichaud, 2009; Goldman et al., 2002; Tsagkas et al., 2014; Franza and Fanjoy, 2012). Marais and Robichaud (2009) showed that in commercial aviation, maintenance-related accidents were more deadly than accidents in general, and that in a maintenance-related accident, the risk was dependent on the nature of the maintenance activity. Goldman et al. (2002) showed that 7% of GA accidents between 1988 and 1997 could be attributed at least in part to a maintenance-related cause or factor. Their findings revealed that the most common accident cause factors involved installation errors, general maintenance, and maintenance inspection. Tsagkas et al. (2014) identified specific factors that guided maintenance technicians towards alternative courses of action during maintenance activities. Franza and Fanjoy (2012) conducted a statistical study on the probable causes for accidents involving Cirrus SR20 and Piper PA28-161 aircraft. They found that mechanical malfunction (not specified further) accounted for 20% of the probable causes for fatal accidents in the PA28-161 fleet.

The human role in aircraft maintenance has received attention from multiple researchers. Fogarty and Saunders (2000) used the SHEL (software, hardware, environment, and liveware) model to classify 250 military aviation incidents in Australia between 1996 and 1998. They reported that *inadequate supervision* (40.4%) by supervisors and *incorrect procedures followed* (32.0%) by maintenance personnel were the most common maintenance errors. Rashid et al. (2010) analyzed 58 helicopter accidents that (1) were exclusively maintenance related and reflected human factors issues, (2) occurred in 1995–2005, (3) involved maintenance crew with similar training, resources, and technical competence, (3) and represented currently used helicopters. Unsurprisingly, they found that when parts failed due to unsafe maintenance actions, the failed parts were more likely to be those that required higher cognitive skills during assembly, installation, alignment, or adjustment.

Some studies have looked into the role of maintenance specifically in helicopter accidents. Haaland et al. (2009) identified 59 tour-helicopter crashes in Hawaii between 1981 and 2008, and found that 34 (~58%) of the accidents were due to poor maintenance. Baker et al. (2011) investigated 178 helicopter crashes related to the oil and gas operations in the Gulf of Mexico in 1983–2009. Their analysis revealed that 10.3% of the accidents associated with mechanical malfunctions were due to maintenance errors. They found that critical rotorcraft systems such as main rotors and transmission systems were most often exposed to maintenance errors. Majumdar et al. (2009) analyzed causal factors for 237 helicopter accidents in the United Kingdom in 1986–2005, and 54 in New Zealand in 1996–2005. They concluded that despite improvements in the reliability of rotorcraft engines, engine failure continued to be one of the main causes for maintenance-related, rotorcraft accidents.

In summary, I reviewed multiple historical studies that directed their efforts at improving GA and helicopter safety. They highlighted loss of control (LOC), controlled flight into terrain (CFIT), flight into poor weather, and engine failure among the top reasons for helicopter accidents. Researchers in these studies focused their attention on specific sources of helicopter accident risk such as mechanical failures, mission types, and injury severity. Many of these studies tended to identify "a root cause" or "an initiating event" for accidents. Generally, these studies lacked multi-year reviews (with the exception of Harris et al. (2012) and Bazargan et al. (2012)); making it difficult to discern any trends in accident causation. As noted earlier, many studies focused on accidents that involved fatalities. Comparing the causes for fatal and non-fatal outcomes could potentially yield valuable insight into unsafe situations during flight.

## 2.2 Literature on GA Flight Data Recorder (FDR) Data Analysis

To improve safety levels, regulators and safety analysts called for a shift from *reactive* to *proactive* safety management techniques. While the former technique responds/makes adjustments to operations/processes after an unacceptable outcome (e.g., accident), the latter makes adjustments to operations/processes before anything bad happens. Flight Data Monitoring (FDM) provides one such avenue for proactive flight safety. Flight Operations Quality Assurance (FOQA) or FDM is a process in which flight data is captured and analyzed to improve flight operation safety. The International Helicopter Safety Team (IHST) defines Helicopter Flight Data Monitoring (HFDM) as "*a systematic method of accessing, analyzing and acting upon information obtained from flight data to identify and address operational risks before they can lead to incidents and accidents*" (IHST, 2009). Proactive FDM techniques rely on the collection and analyses of flight data records to identify hazardous patterns during flights and/or key flight parameters to monitor.

There have been some studies on the safety of commercial operations by analyzing Flight Data Recorder (FDR) data. Li and Hansman (2011, 2013) used a combination of data mining algorithms and expert review to identify anomalies during flight, such as low altitude and slow speed during approach, from a set of 365 B777 flights with various origins and destinations. Cohen et al. (1999) and Smith et al. (2000) developed and tested an aircraft performance risk assessment tool. They used aircraft Quick Access Recorders (QAR) and Flight Operational Quality Assurance (FOQA) data to calculate the risk of Controlled Flight into Terrain (CFIT) accidents from a combination of safety events. The output of their risk model provides an estimate of severity, consequence, and probability of occurrence.

While many operators in the commercial aviation sector have embraced FDM analysis, applying these techniques in the GA sector poses technical, economic, and operational challenges. Challenges include the diverse GA fleet composition, ageing GA fleet, costs of upgrading/retrofitting existing GA aircraft, and complex nature of GA missions (e.g., GA operations do not necessarily follow well-defined phases of flight like in commercial operations).

Recognizing the potential safety improvements from FDR data analysis, the FAA recently initiated projects [Safety Analysis for General Aviation (SAGA) and Rotorcraft-Aviation Safety Information Analysis and Sharing (R-ASIAS)] to collect and build a database of voluntarily-contributed FDR data.

Initial research using GA-FDR data has shown promise (e.g., Goblet et al., 2015; Harrison et al., 2015, Puranik et al., 2016a; Puranik et al., 2016b). Goblet et al. (2015) highlighted the challenges associated with fixed wing GA operations and proposed a set of algorithms to identify flight phases as a first step in identifying non-nominal events (or safety events) during flight. In an effort to characterize unsafe behavior during the approach phase of flight, Fala and Marais (2016) analyzed FDR records from 23 instructional flights. They suggested refinements to the existing safety event definitions and called for the creation of pilot-friendly safety metrics. Related research by Puranik et al. (2016b) used energy management techniques to define a “nominal” or safe approach profile for GA aircraft.

There has been limited research in analyzing (non-military) helicopter flight data records. Gavrilovski et al. (2016) used a model-based approach for safety event definitions. They used a lateral dynamic model along with flight data to identify potential precursors to a dynamic rollover. They also developed a helicopter performance model to assess safety during autorotations. In this approach, they used the performance model in conjunction with flight data to estimate flight parameters that were not captured by the on-board FDR.

## 2.3 An Overview of Accident Modeling

Literature on accident causation and modeling is extensive, but often fragmented. This chapter begins by providing an overview of accident modeling. Then, I review key modeling theories[6] that have shaped our understanding of aviation accident causation, and conclude this chapter by comparing and contrasting the different modeling techniques.

Accident models help us better understand the causal mechanisms in accidents during post-hoc analysis. They aid in depicting the relationship between causes and consequences (outcomes of an accident), and are frequently used as tools in understanding and assessing the risks associated with a system.

Figure 2 summarizes the history and evolution of accident modeling. Initial efforts to understand accident causation viewed accidents as the culmination of a linear sequence of events. These simple linear approaches suggested that accidents could be prevented by eliminating any one of the causes. With time, researchers realized that accidents were more a combination of unsafe actions and latent (or already prevalent) hazards—resulting in epidemiological models. In the more recent past, researchers recognized the need for non-

[6] While this section reviews some of the models used to describe aviation accidents, it does not serve as an exhaustive review of the different accident causation models. The interested reader is pointed to works by Qureshi (2008), Al-shanini et al. (2014), and Salmon et al. (2012) for a more comprehensive review of different models.

linear accident models. These models attempt to capture the interactions between the different components and actors in a system (operating in a particular environment).

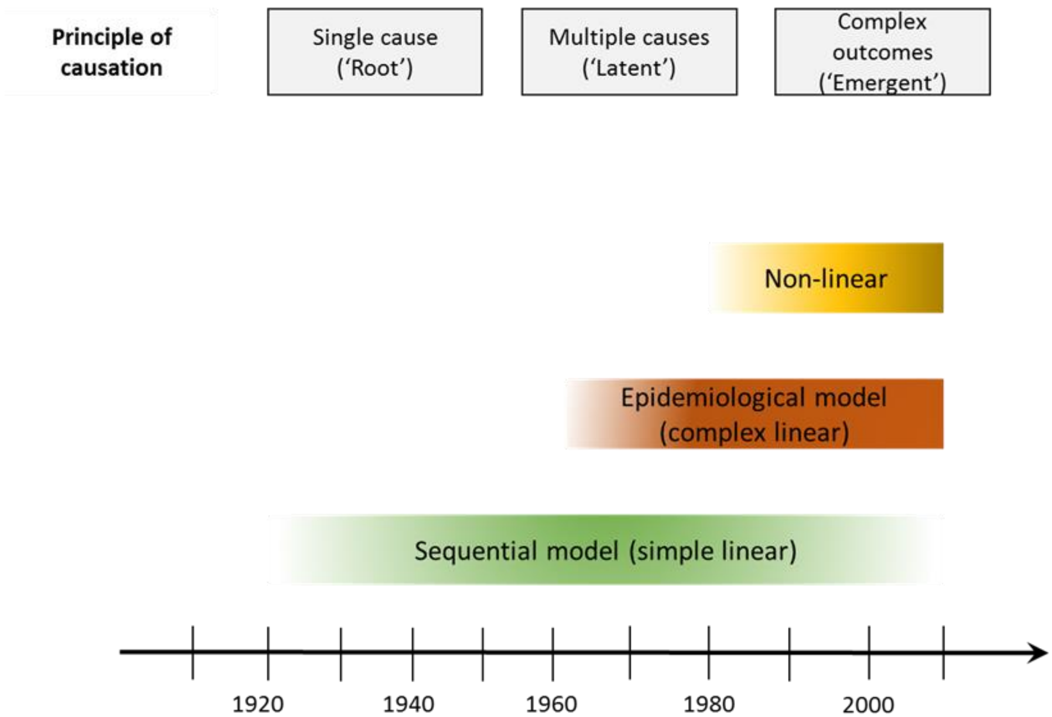


Figure 2: Summary of accident model methods [adapted from (OHS, 2012)].

The Domino model proposed by Heinrich et al. (1931) in the 1940s was among the first accident models. This model represents accidents as a sequence of discrete events that occur in a particular order. Heinrich's model falls under the category of other sequential event-based models such as Fault Tree Analysis (FTA), Event Tree Analysis (ETA), and Failure Modes and Effects Analysis (FMEA). While these models help represent simple accidents, they cannot explain accidents in complex systems.

Efforts to explain accidents in complex systems paved the way for a new class of accident models called epidemiological models. This class of models, as the name suggests, borrowed ideas from the field of medicine and disease prevention. Epidemiological models attempt to explain accident causation as a combination of active and latent factors that come together at a particular instant of time. One of the noteworthy models of this class is Reason's "Swiss Cheese Model", which highlights the relationship between proximate causes and latent factors. Reason's model is widely used by the aviation industry to explain accident causation. Later in this Chapter, I present the merits and shortcomings of this model.

Traditional accident modeling approaches tended to focus on component or hardware failure, and employed the analytic reduction principle[7] (Leveson, 2016). These approaches often failed to consider the role of human or social factors in accidents. Complex sociotechnical systems exhibit non-linear relationships and dynamics between components (technical, human, and organizational). These relationships are not captured by sequential or epidemiological models. A new class of models based on systems theory or systemic models was developed to model the behavior of complex sociotechnical systems. Sociotechnical models are an improvement over the sequential models because they describe accidents using complex networks of events rather than simple cause-effect chains. Some of the noteworthy systemic models include Rasmussen's hierarchical sociotechnical network and Leveson's Systems Theoretic Accident Model and Process (STAMP).

[7] The analytic reduction principle involves: (1) breaking down the system into individual parts; (2) analyzing each of the parts independently; and, (3) combining the different parts to provide results for the whole system (Leveson, 2016).

Section 1.3 describes the various traditional accident modeling approaches that viewed accidents as a linear combination of events. Section 1.4 presents accident models that are based on systems theory[8].

## 2.4 Linear and Epidemiological Accident Models

### 2.4.1 Domino Model

This model explains accidents as a chain of discrete events that occurred in a particular order. Heinrich's Domino Theory was among the earliest event-based models. It compared an accident sequence to five dominoes shown in Figure 3. This model suggests that the social environment leads to fault of the person, which in turn is the proximate cause for unsafe act or condition. This unsafe act/condition leads to an accident, which results in injuries (Figure 2).

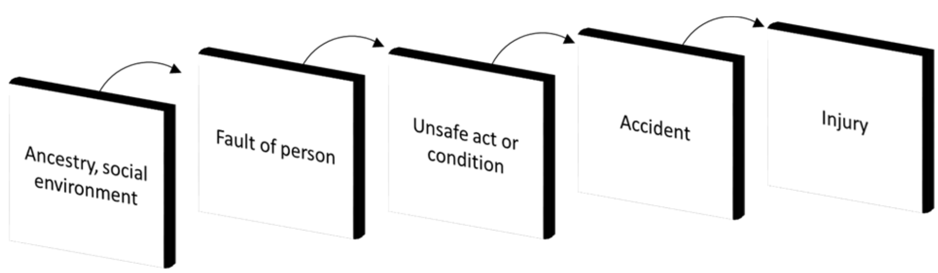


Figure 3: Heinrich's Domino Model of accident causation [adapted from Leveson (2001)].

This model suggests that there exists a single cause that triggered the sequence of events leading to the accident, and that eliminating this root cause could prevent future accidents; however, most accidents generally involve multiple causes. Focusing our efforts on eliminating a single cause might lead to missed opportunities (missing other relevant

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[8] In contrast to analytic reduction, systems theory views the system as a whole, and not as individual parts. One of the basic tenets of systems theory is that "the whole is greater than the sum of the individual parts.

causes), thereby not helping prevent future accidents. Leveson (2001) and Perrow (1984) cite the example of the DC-10 crash at Chicago O'Hare in 1979 to highlight the peril of focusing on a single cause. In this accident, the National Transportation Safety Board (NTSB) blamed a "maintenance-induced crack" as the reason behind the accident. However, the NTSB failed to identify "faulty design" as one of the reasons for the accident, leading to future accidents with the same design flaw.

### 2.4.2 Fault Tree Analysis

A fault tree is a logical diagram that is used to represent the relationship between a system failure and the causes for the failure (Qureshi, 2008). It is a deductive analysis that looks "backward" at the causes for an undesired event. Some of the key objectives of an FTA include: (1) identifying the causes of a failure; (2) expose weaknesses in the operation and design of the system; (3) prioritize the reason for failures; and, (4) calculating failure probabilities (Vesely et al., 2002).

This technique employs Boolean logic (e.g., AND, OR gates) to analyze and model accidents. This technique begins by identifying an undesired event for a system, and then resolving the undesired event into its causes. The event is resolved until the "basic" causes are deduced from the logical event tree (fault tree).

### 2.4.3 Chain of (Time-Ordered) Events

The chain of events model, in which accidents are represented as a series of time-ordered events, is one of the most commonly used accident models. These events almost always include human error or mechanical failure. Unlike the domino model that considers only a single chain of events, the event-based model can also include multiple event sequences in the form of parallel or converging chains. For example, the Multiple Events Sequencing (MES) model includes a time sequence of events and conditions associated with each actor in an accident (Benner, 1975).

The relationship between the events in a chain of events model is generally linear, suggesting that a preceding event must be present in order for the subsequent event to happen. It is difficult (if not impossible) to capture the non-linear of accident causation in complex systems. This model also suffers from backward chain propagation, where the assignment of an initiating event can be arbitrary as it is dependent on the stopping point when going backward in the event chain.

### 2.4.4 Swiss Cheese Model

Reason explained accident causation in complex sociotechnical systems using an organizational model. The organizational view recognizes that accidents are generally not caused by a single error; rather they are caused by a combination of errors that occur at different levels of the organization. Reason (1997) describes organizational accidents as: Situations in which latent conditions that arise from aspects such as management decisions that combine adversely with local triggering events (e.g., weather) and with active failures (errors and/or procedural violation) committed by individuals or teams at the sharp end of an organization, to produce the accident (Qureshi, 2008).

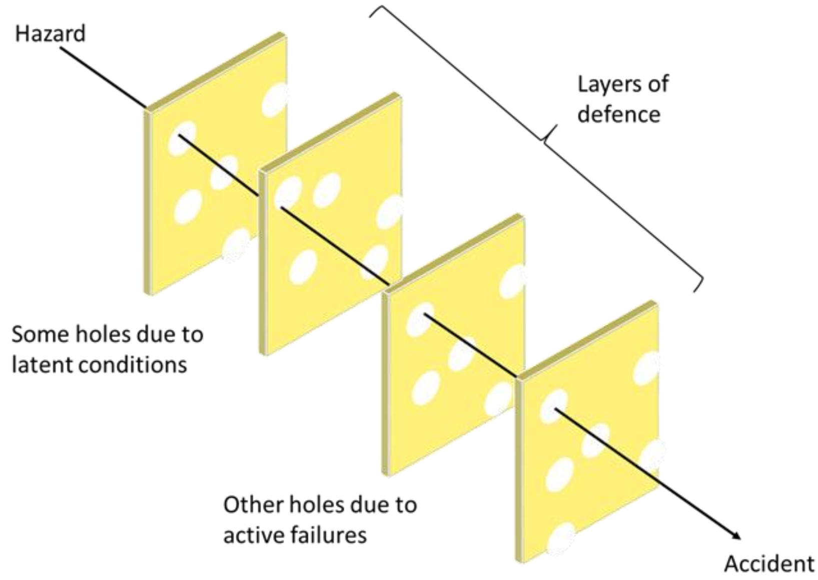


Figure 4: Reason's Swiss Cheese Model [adapted from Reason (1998)].

This model represents the safeguards (or defences) as layers of cheese that are superimposed over each other as shown in Figure 4. The holes in the defences arise due to either latent[9] (e.g., decision made by designers) or active failures (e.g., slips, fumbles, violations). Accidents occur when the holes in the different layers of cheese line up—releasing the accident trajectory.

Unlike the chain of events model, which focuses on error events in a chain leading up to the accident, the Swiss cheese model focuses on the system's role in accident occurrences and prevention. The preventive measures from the Swiss cheese model include changes to the operating conditions, organizational decisions, system configurations, and improving the defences against accidents.

[9] Latent conditions are sometimes referred to as "resident pathogens". These pathogens arise from decisions made by management, designers, or builders. These latent pathogens may remain dormant in the system for many years before combining with active failures and local triggers to result in accidents

Despite wide application of Reason's model, there are also many criticisms of the model (Dekker, 2002; Qureshi, 2008; Luxhoj and Kauffeld, 2003; Shappel and Wiegmann, 2000). Multiple researchers (Shappel and Wiegmann, 2000; Dekker, 2002) suggested that the model does not describe in sufficient detail the nature of the holes in the Swiss cheese. Luxhoj and Kauffeld (2003) stated that the inability of the model to account for the interrelationship between the different causal factors reduced the practical significance of the model—a view echoed by Shorrock et al. (2003). Saleh et al. (2013) suggested that the frequent use of the Swiss cheese metaphor might have resulted in a flawed understanding of accident causation. They added that Reason's model might have contributed to a false impression that an accident sequence is instantaneous (when the holes line-up) and does not progress in jerks, which is often the case. Young et al. (2004), while not advocating discarding the model, called for increased awareness among investigators about the applicability of the model and to not adhere to it "dogmatically". This model does not help better understand an accident—for example, **why** did the holes form, or **why** did the holes line up (even if in jerks). All it really does is explain why things can be wrong (the holes) and yet nothing bad happens (the holes have not lined up yet).

### 2.4.5 Human Factors and Classification System (HFACS)

Building on the model proposed by Reason, Shappel and Wiegmann (2000) developed the Human Factors Analysis and Classification system. They used this system to not only categorize unsafe acts by the human operators at sharp end of the accident, but to describe the pre-conditions for these unsafe acts. Figure 5 illustrates the HFACS framework.

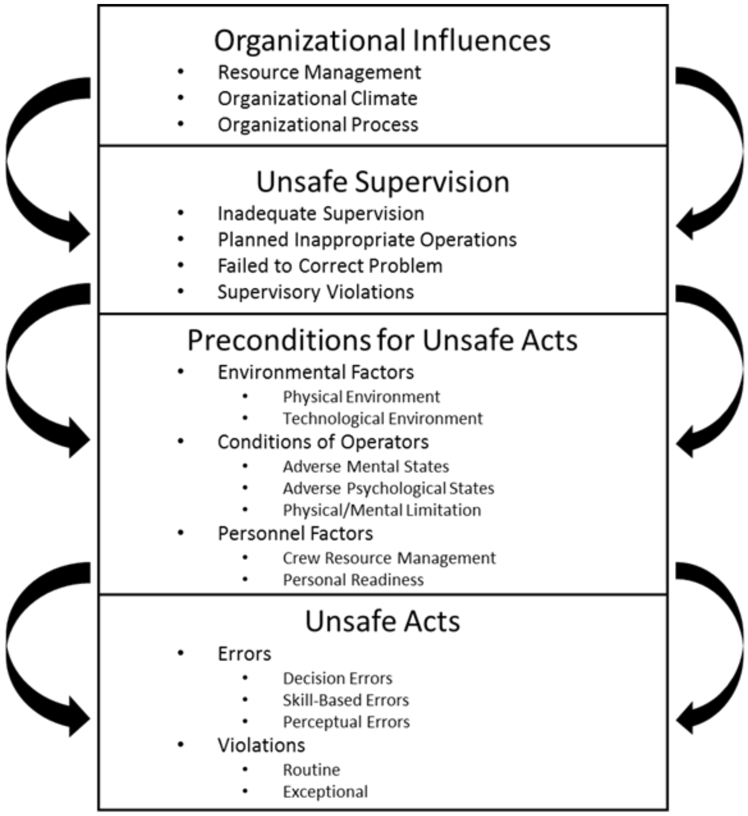


Figure 5: Human Factors Analysis and Classification System (HFACS) [adapted from (Shappel and Wiegmann, 2001)].

Unsafe acts are the lowest level of the framework. Unsafe acts can be broken down into errors or violations. *Errors* represent the activities that fail to achieve the intended outcome, and *violations* refer to the disregard for rules and regulations (Shappel and Wiegmann, 2001). The further classify errors as *decision-based*, *skill-based*, and *perceptual* errors. Violations are classified as routine (or habitual) and exceptional (or one-off). To illustrate the difference between the two types of violation, Shappel and Wiegmann provide the example of motorist violating speed limits. They state that driving at 64 mph in a 55 mph speed zone, while considered a violation, is acceptable to the authorities. However, driving at 105 mph in a 55 mph zone is a gross violation (of an isolated nature) of the speed limit, and is unacceptable to the authorities.

*Preconditions for unsafe acts* constitute the second level of the HFACS framework. As the name suggests, this level identifies substandard operating conditions and poor practices followed by the operators.

The third level, *unsafe supervision*, highlights supervisory shortcomings and their influence on safety. Unsafe supervision is further classified as: (1) inadequate supervision; (2) planned inappropriate operations (e.g., overworking employees); (3) failure to correct problem; and, (4) supervisory violations. Supervisory violations occur when the management is aware of an existing problem, but it chooses to disregard the rules and continue operations.

The top most level of the HFACS framework is used to identify *organizational influences*. This level can be broken down into resource management, organizational climate, and organizational process. The framework shows that the decision and policies of the upper management percolate down to the lower levels. Incorrect handling of resources (monetary, equipment, and human), improper use of authority (or failure to claim responsibility), and insufficient safety management can result increased organizational risk.

## 2.5 Systemic Accident Models

Accident models based on systems theory are termed systemic models. One of the key differences between systemic and epidemiological/sequential accident models is that the former attempts to describe an accident as a complex network of human-machine interaction while the latter represents accidents as a simple cause-effect sequence. Some noteworthy systemic accident models are Rasmussen's (1997) hierarchical socio-technical framework (and *Accimap*) and Leveson's (2004) systems theoretic accident modeling and process (STAMP). Some accident models such as Hollnagel's (1998 and 2004) Cognitive

Reliability and Error Analysis Method (CREAM) and Functional Resonance Accident Modeling (FRAM) focus on human performance and cognitive abilities while operating complex systems.

### 2.5.1 Rasmussen's Socio-Technical Framework and AcciMap Method

Rasmussen developed a systems-based framework that modeled different levels of a system (e.g., government, regulators, organization, management, staff, and work). He considered system safety as a property that emerges from the various interactions between the different levels of the system.

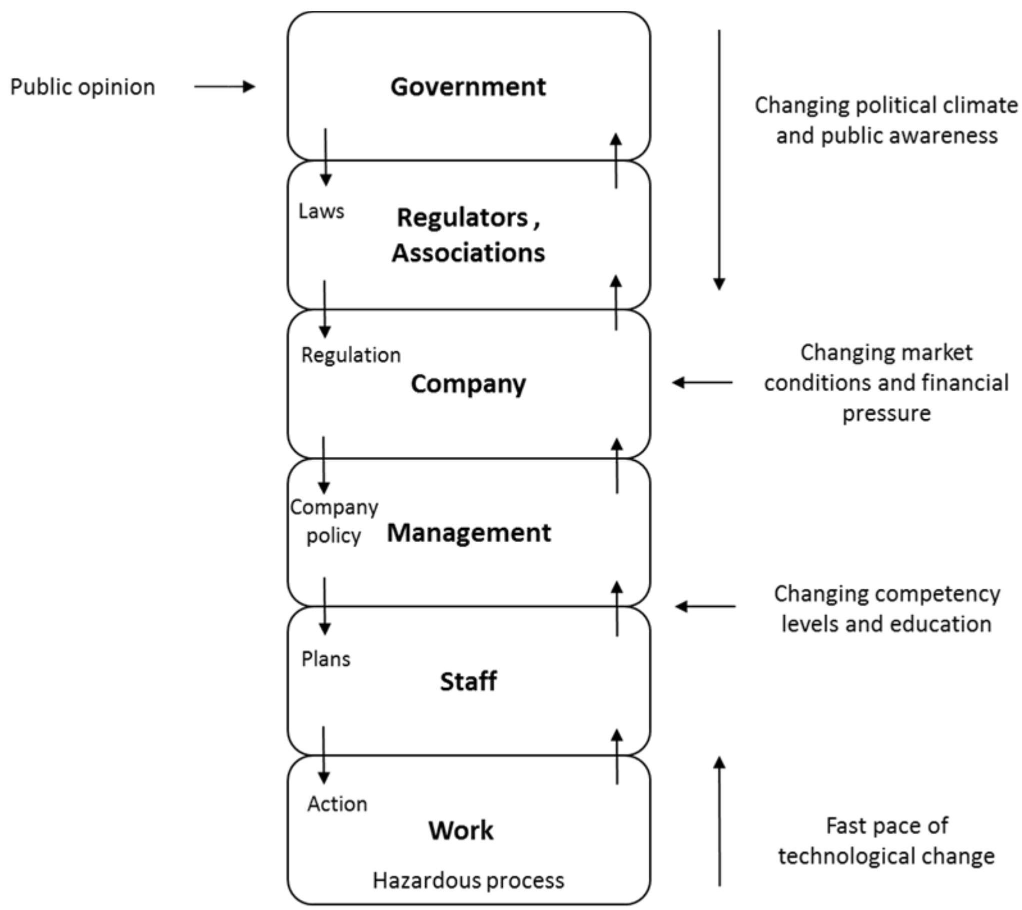


Figure 6: Rasmussen's risk management framework [adapted from Rasmussen (1997)].

Figure 6 shows the hierarchical model of this socio-technical model used in risk management. Level-1 represents the government, which controls safety through legislation. Level-2 represents the regulators who implement the legislations prescribed by the government. Level-3 describes the activities of a company, while level-4 represents the company management and the decisions that influence the working of their employees/staff. Levels 5 and 6 represent the actions taken by company staff when working with machines/technology, and the application of engineering disciplines in designing the machines, respectively. The arrows represent the flow of information between the different levels. According to this framework, a system can operate safely when legislations, regulations, and decisions made at the higher levels of the system are reflected through the actions of employees. Similarly, information about the system at the staff level should flow up the hierarchy to inform decisions taken at the higher levels.

Figure 6 also shows that various environmental stressors can affect different levels of the system at any instant of time. For the system to remain safe, the different levels would need to coordinate with each other and balance the constraints imposed at each level.

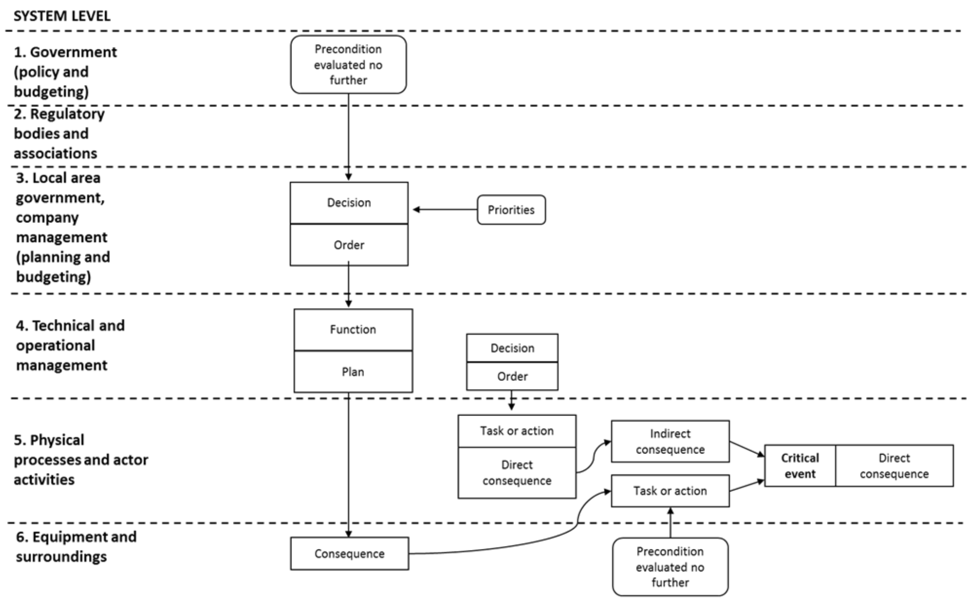


Figure 7: Rasmussen and Svedung's AcciMap model for analyzing accidents [adapted from Underwood and Waterson (2014)].

Rasmussen and Svedung (2002) developed *AcciMap* as a control theory-based systems thinking approach to modeling accidents (Underwood and Waterson, 2014). Accimap provides a graphical representation of the failures in a system, and the actions/decisions that precipitated the failures. It combines the cause-consequence chart and risk management framework (Rasmussen, 1997). Investigations that use Accimap (Figure 7) generally focus on six organizational levels: (1) government policy and budgeting; (2) regulatory bodies and associations; (3) local area government, company management planning and budgeting; (4) technical and operational management; (5) physical processes and activities; and (6) equipment and surroundings.

### 2.5.2 System-Theoretic Accident Modeling and Process (STAMP)

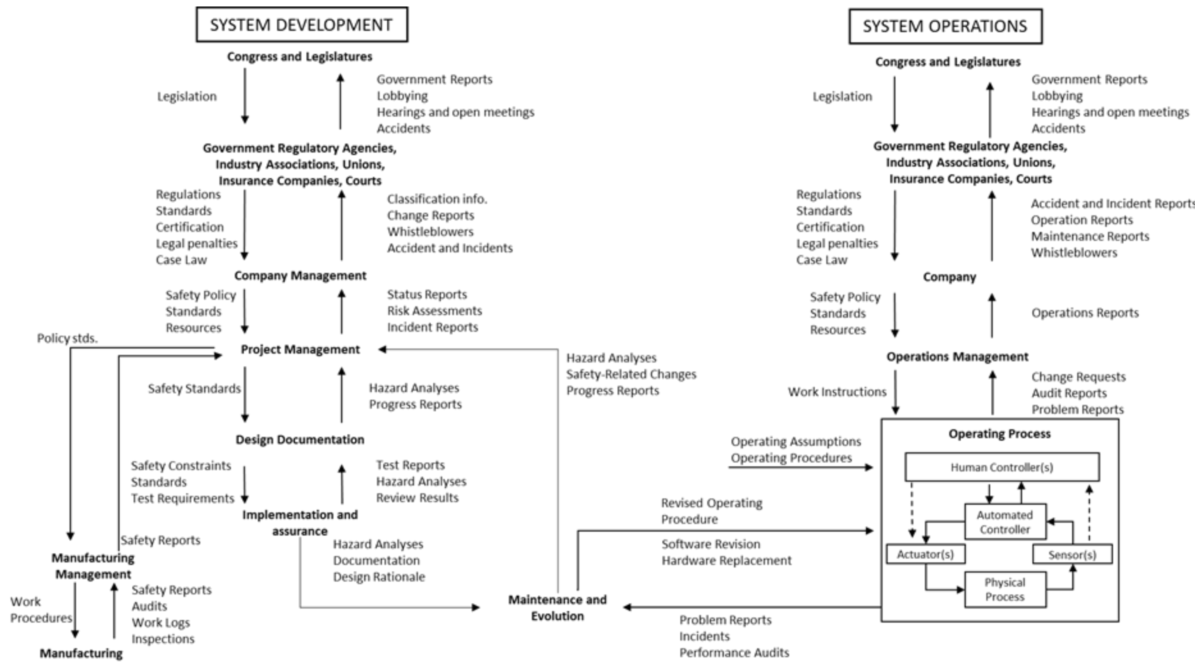


Figure 8: Hierarchical safety control structure in the STAMP model [adapted from Leveson (2004)].

Leveson (2004) proposed the Systems-Theoretic Accident Modeling and Process (STAMP) to analyze accidents using a systems theory approach (Figure 8). This approach views system safety as a control problem where an accident is caused due to failed enforcement of safety-related *constraints* at various levels of a socio-technical system. This model can also help demonstrate how complexity within a system influences events leading up to an accident (Underwood and Waterson, 2014)[10].

STAMP helps provide a description of a system's control structure, and helps identify failures in the different levels of the system that contributed to the accident. As shown in Figure 7, the STAMP model has a *system development* and *system operations* control

[10] The interested reader is directed to Underwood and Waterson (2014) for a more comprehensive application of the STAMP model. They compared and contrasted multiple accident models while analyzing the Grayrigg rail accident that occurred in the UK in 2007.

structure. Leveson (2004) gives the example of an aircraft manufacturer to explain the working of the model. While the aircraft manufacturer has the development of the system under its control, system operation is the domain of the aircraft operator (e.g., airline). Leveson added that system safety could be achieved by interaction between the two control structures (as depicted in the lower half of Figure 8)—by designing safety into the system, and by correct operation. This model facilitates iterative improvement of safety through a dialogue between manufacturers and operators. The manufacturers communicate some of the assumptions about the operating environment, and the operators provide feedback about the system's performance in the actual environment.

### 2.5.3 Cognitive Reliability and Error Analysis Method (CREAM)

Hollnagel (1998) proposed CREAM as a practical approach to analyze the cognitive performance of a human operator, predict the probability of an error by the operator, and assess the consequences on the system. It can also be used for retrospective analysis of accidents. This technique comprises a human error classification scheme and a model.

CREAM employs the Contextual Control Model (COCOM), which focusses on the actions that are chosen by an operator (Figure 9). The four control modes that are specified by the control model are: (1) scrambled; (2) opportunistic; (3) tactical; and, (4) strategic. A comprehensive description of these control modes can be found in Hollnagel (1998, pp. 155–157). COCOM assumes that an operator has variable degrees of control over his actions, and that the level of operator performance is directly proportional to the degree of control over the actions (Hollnagel, 1998).

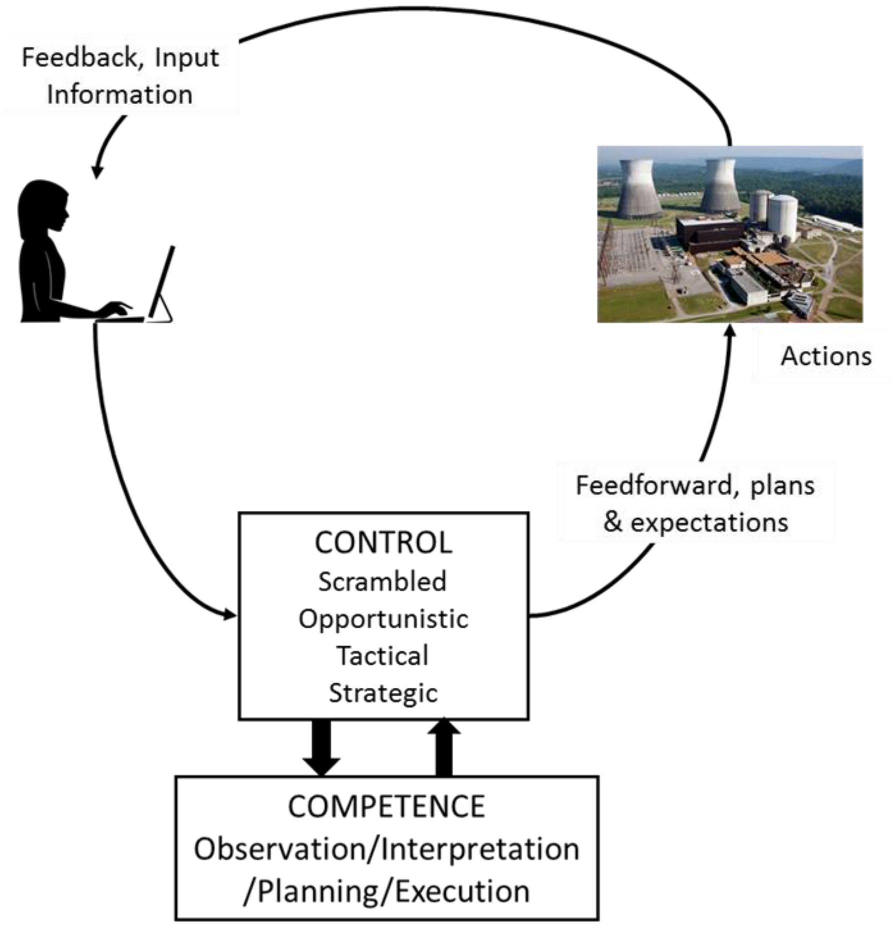


Figure 9: The Contextual Control Model (COCOM) [adapted from Hollnagel (1998)].

This approach allows for the classification of human action into groups that help describe the *phenotypes* (error mode) and *genotypes* (causes)[11] of these actions. There are eight observable phenotypes in CREAM (i.e., timing, duration, sequence, object, force, direction, distance, and speed), which can be further divided into four sub-groups that further describe the nature of the erroneous action. It classifies the phenotypes of causal mechanisms into either individual, technological, or organizational. In addition to the error modes and their

[11] Hollnagel (2016) describes *phenotypes* as the observable forms of erroneous actions, while *genotypes* refer to the mechanism for erroneous actions. Saleh et al. (2010), in their review of accident literature, state that *phenotypes* represent threshold-based classification of accidents (e.g., based on severity), while the accident *genotype* represents the fundamental mechanism of an accident. Both sets of authors agree that while phenotypes are observable, genotypes can only be inferred.

underlying causes, CREAM uses a set of common performance conditions (CPC) that help the investigator/analyst describe the context in which the erroneous action was carried out.

### 2.5.4 Functional Resonance Accident Modeling (FRAM)

Building on the work in CREAM, Hollnagel (2004) proposed the Functional Resonance Accident Modeling (FRAM) technique in 2004. This technique attempts to describe variability in human performance using the idea of functional resonance. Hollnagel suggests that successes and failures do not result from actions that are fundamentally different. He adds that while the outcomes might be different, the underlying process does not necessarily change. He argues that success and failure are emergent phenomena that result from human performance variability while performing these actions. A combination of the variabilities in different functions could reinforce (or resonate) the variability in a specific function.

A FRAM-based analysis consists of four steps: (1) identifying key system functions and characterize the functions using six basic parameters[12]; (2) use a checklist to identify potential variability; (3) identify dependencies between the different functions and define functional resonance; and, (4) suggest potential barriers and performance monitoring strategies.

This technique helps provides a better understanding of the working of a complex socio-technical system. It does not specify the characteristic of each component in the system, thereby avoiding the tendency of "identifying a solution for each cause" (Hollnagel, 2016).

[12] The six basic parameters are obtained from the Structured Analysis and Design Technique (SADT). They are: (1) inputs; (2) outputs; (3) resources; (4) controls/constraints; (5) preconditions; and, (6) time. Hollnagel (2013) provides detailed explanation of each of the parameters.

One of the major shortcomings of this approach is that it is time-intensive. The qualitative nature of the FRAM analysis raises questions about the applicability of this approach in quantifying failure; for example, the probability of a component failing.

## 2.6 State-based Accident Modeling

State-based models find their origins in finite state machines. State-transition diagrams have been extensively used in the software domain to develop and understand software interfaces, and interactive systems. Harel (1987) introduced the statechart formalism to aid with the design of complex discrete-event systems. Statecharts extended the capabilities of finite state machines by avoiding the "exponential blow-up" problem—a scenario where the number of possible states for a system grows exponentially.

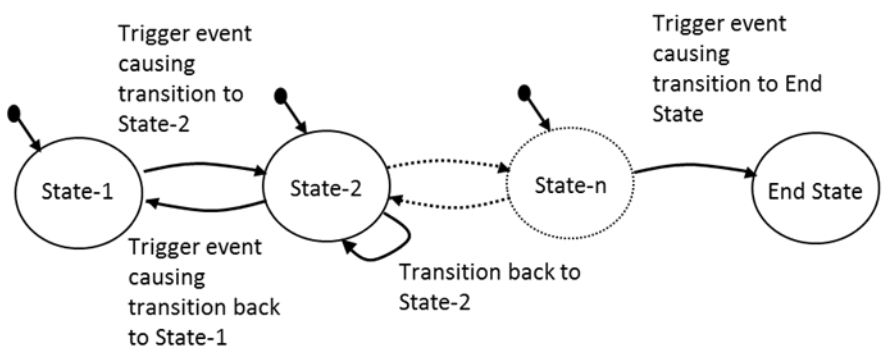


Figure 10: Generic state-based representation of a system.

Figure 10 shows a generic state-based representation of a system. *States* are segments of time wherein a system exhibits a particular behavior. Control theory literature (Chen, 1995) defines "the *state of a system* at time $t_0$ is the information at $t_0$ that, together with the input $u(t)$, for $t \geq t_0$, determines uniquely the output $y(t)$ for all $t \geq t_0$." The nodes in Figure 10 represent the different system states. The arrow at the top of each node represents a possible "*default or start state*" for a system. *Triggers* occur at precise instants of time and cause a system to *transition* between states. The links with arrows represent state *transitions*. A system can transition between states or self-transition, where it goes back to the same state. In Chapter 4, I provide a detailed explanation of a state-based model applied to historical accident data.

Some researchers have used state-based approaches to model system safety (e.g., Ariss et al, 2010; Reif et al., 2010; Landry et al., 2009; and Jian, 2011). In an effort to integrate fault trees into statecharts, Reif et al. (2000) used the example of a radio-controlled railway crossing. They suggested that fault trees and statechart models of a system should be constructed separately; however, the construction of both models should be interdependent. Building on this work, Ariss et al. (2010) successfully integrated fault trees and statecharts. They provided a set of state-transitions rules to model the logic gates that appear in fault tree analysis (FTA). They demonstrated their approach by modeling the failure of gas burner unit.

Favaro' and Saleh (2016) used a control-theoretic approach to model system safety. Their research used a state-space formalism to model the dynamics of a system. They defined set of equations that modeled the different states of a system (over a period of time), and used this information (about the states) to identify and monitor the "hazard levels" of the system, and to develop a "time-to-accident" metric.

Some studies have applied a state-based approach to model air traffic safety (e.g., Landry et al., 2009; Jian, 2011). Landry et al. (2009) modeled human-integrated systems to using modified statecharts. They defined safety of the system as the ability of an agent (human or automated) in the system to control the state of the system such that it does not reach an "undesirable" or "unsafe" state. To make the distinction between states from which a system cannot recover (e.g., midair collision) and their precursor states (e.g., loss of separation), they termed the unrecoverable states as unsafe and the precursor states as undesirable. They leveraged the *orthogonal*[13] property of statecharts to represent the current and future states of a system. They specified a set of conditions, which when satisfied, permitted the transition from one state to another. In addition to developing a predictive model, the researchers demonstrated the capability of their approach to be used with conventional reliability-based calculations.

## 2.7 Summary

In this chapter, I reviewed several key accident models; many of these models have been used to analyze aviation accidents. This section summarizes the different accident models presented in Sections 2.4 and 2.5. Table 2 serves as a quick reference guide on the characteristics, merits, and shortcomings of different accident model.

Table 2: Summary of Accident Models

| **Accident Model** | **Description** | **Shortcomings** |
|---|---|---|
| Domino model (Heinrich, 1931) | Describes accidents as a sequence of five factors including social environment, personnel fault, unsafe conditions or actions, and injury. | • Suggests that accidents result from a single cause<br>• Attributes accidents to human error or failure |

[13] Harel (1987) defines the orthogonal property of statecharts as being in a state where the system must be in all of its AND components. In other words, if a system state **A** can be divided into two components **C** and **D**, then the system can enter state **A** only if enters each of the components **C** and **D**. The interested reader is directed to Harel (1987, pp. 242–250) for a more comprehensive explanation.

| Accident Model | Description | Shortcomings |
|---|---|---|
| Chain of events | Describes accidents as a sequence of time-ordered events. It considers human and mechanical failure. Accidents can be represented by multiple chains. | • Linear model which suggests that the preceding event needs to be present for the subsequent event to happen<br>• Assumes that "breaking the chain" by eliminating one of the events (links) can prevent an accident<br>• The assignment of an initiating event can be arbitrary as it is dependent on the stopping point when going backward in the event chain |
| Fault Tree Analysis | A deductive method to identify the most basic causes for an accident. It represents an accident by a tree diagram that uses Boolean logic. | • Assumes linear relationship between causes and accident<br>• Fault trees can get large and complicated for a large system<br>• Difficult to apply to systems/sub-systems that can operate with partial failure |
| Swiss Cheese model (Reason, 1998) | An epidemiological model that represents that barriers between a hazard and accident by slices of Swiss cheese. The holes in the cheese slices represent the latent conditions (or resident pathogens). An accident occurs when the holes in the cheese align. | • No clear description of the holes in the cheese, or when and why they appear<br>• Incapable of identifying relationship between the different causes<br>• Can lead to misinterpretation that all accidents result from mistakes by management |
| Rasmussen's model (Rasmussen, 1997) | System-based framework where risk management is viewed as control problem where injuries and damage result from a loss of control of the physical process. It is difficult to establish a fixed procedure in a dynamic environment. Accidents take place when there is a loss of control at the safety boundary | • This model is qualitative in nature. It does not provide mathematical basis for predictive analysis<br>• Relies on detailed information in accident reports<br>• Problematic to apply to large-scale accident analysis |

| Accident Model | Description | Shortcomings |
|---|---|---|
| STAMP<br>(Leveson, 2004) | A system-theoretic approach that uses elements of Rasmussen's model. Views system safety as a control problem where an accident is caused due to failed enforcement of safety-related *constraints* at various levels of a socio-technical system. | • Dependent on detailed information from accident reports<br>• Qualitative model that makes it difficult to apply techniques to large scale accident data analysis |
| CREAM<br>(Hollnagel, 1998) | Hollnagel developed CREAM to model human performance, and potentially predict the probability of an error being committed. This model focuses more on the impact of human performance on a system, and does not consider technical aspects. This model can be applied to qualitative and quantitative analyses. | • Can be complicated and time consuming to implement<br>• Does not suggest remedial measures to improve human performance<br>• Requires domain-specific knowledge; i.e., human factors and human cognition |
| FRAM<br>(Hollnagel, 2004) | FRAM is a qualitative accident model that attempts to describe variability in human performance using the idea of functional resonance. It helps develop a better understanding of the working of a complex socio-technical system | • Qualitative approach that can be highly time consuming<br>• This model does not allow for conventional probabilistic failure analysis—focuses on likelihood of human performance variability |

# CHAPTER 3. NTSB ACCIDENT DATABASE AND OCCURRENCE CHAINS

This chapter discusses the NTSB's accident database and the use of occurrence chains to understand accident causation. Most helicopter accident research focuses on single root causes or most frequent causes for accidents. In this chapter, I attempt to better leverage the information in the accident database by identifying the "stories" (or trajectories) associated with each accident. Sequences of occurrences (or occurrence chains) represent these accident trajectories. Specifically, I seek an answer to the following question:

*Can we learn more about GA accident causation by counting and comparing these occurrence chains?*

The first part of this chapter serves as a quick guide to the NTSB's accident recording system for the past three decades. I also present some of the key issues that analysts should bear in mind during their analyses (and the conclusions that are drawn). The second part of this chapter explores the concept of occurrence chains in helicopter accidents[14]. I present key results and important lessons learned.

## 3.1 Layout of Accident Database

The NTSB established a publicly-available accident database in 1962[15]. Accident investigators enter accident investigation data in a coded format using an automated data entry system (NTSB, 2002). Major revisions were made to the database in 1982, adding

[14] This chapter builds and expands on the work presented in Rao and Marais (2015).
[15] Accidents that occurred before 1982 are beyond the purview of this thesis. The interested reader is directed to Robichaud (2012) for a description of the NTSB database in 1962–1982.

additional features that aided in better describing accidents. The NTSB records accident information on their database, which includes fields related to aircraft type, geographic location of accidents, phases of flight, severity of injuries and damage, crew details, and type of maintenance. In addition to coded information, the database also contains accident narratives, which could potentially provide additional insight into accidents.

The NTSB uses occurrences to summarize the events leading up to the accident. They define an *occurrence as a distinct major event of relative significance that leads to an accident or incident* (NTSB, 1998). Figure 11 summarizes the NTSB accident recording system. Accident reports place each occurrence in a sequence (occurrence chain) leading up to the accident. In general, the final occurrence in a chain can be interpreted as the accident—that is, each preceding occurrence still leaves a possibility (though it may be remote), of escaping without injury or damage.

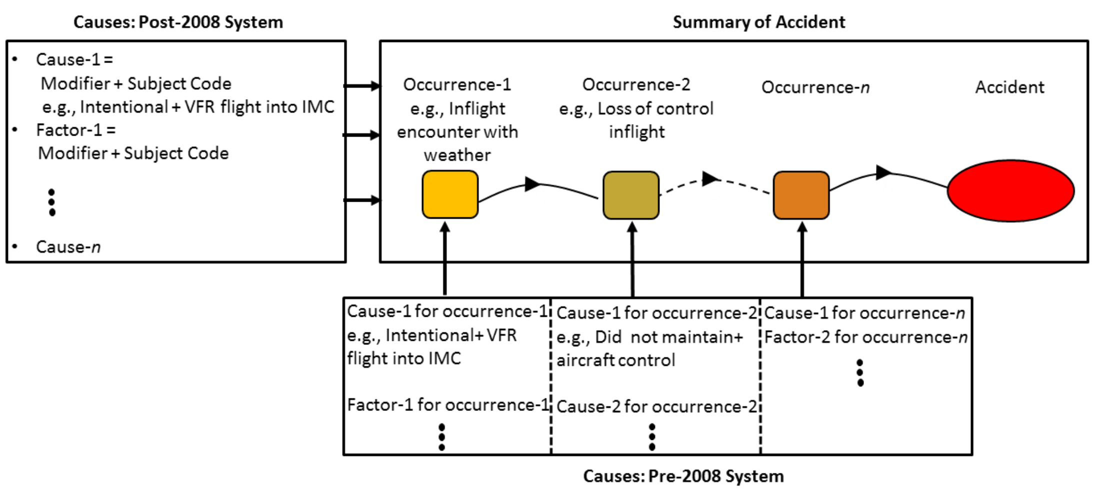


Figure 11: Summary of the NTSB accident recording system.

To record the findings (why the accident happened) for each accident, the NTSB uses *subject codes* and *modifiers*. The subject codes are designated as causes, factors, or events in accidents. For accidents with multiple causes and factors, the NTSB has no provision to show the magnitude of each cause or factor with respect to the others, reflecting the difficulty in assigning proportional blame.

The NTSB produces factual and probable cause reports (usually available online in pdf format) for each accident, and also provides a coded summary in a searchable database format. The probable cause report provides a brief synopsis of the accident and the probable cause statement. The factual report generally provides more detail such as pilot experience and aircraft airframe hours accompanied (usually) by a prose account of the accident.

### 3.1.1 Old System (1982–2008)

Until 2008, NTSB investigators could choose from 54 occurrence codes, 1597 subject codes, and 470 modifier codes to provide summaries of accidents (Figure 11). The NTSB used five-digit *subject codes* accompanied by four-digit modifiers to represent the key findings in accidents. The NTSB classified these subject codes into four sections to describe the nature of the findings (Table 3). NTSB-Sections IA and IB are used to list the primary events/findings that led to the accident. NTSB-Sections II and III are used to further define or explain the primary events or findings.

Table 3: NTSB Accident Classification 1982–2008 (NTSB, 1998)

| **Category** | **Examples** |
|---|---|
| **IA—Primary non-person related findings** | |
| Aircraft Structure | Control surfaces, rudder, fuselage, landing gear |
| Aircraft System | Autopilot, hydraulic systems |
| Power plant | Bleed air system, compressor assembly, fuel system |
| Miscellaneous aircraft/equipment | Lights, coolant, fuel, lavatory |
| ATC/weather/airport facility/equipment | Approach aids, radar, meteorological services |

| Category | Examples |
|---|---|
| Miscellaneous publication | Aircraft manuals, charts and other manuals |
| **IB—Primary person-related findings** | |
| Aircraft/equipment performance | Autopilot, communication equipment, navigation instruments |
| Operations/ATC/Maintenance | Missed approach, aircraft control, compensation for wind |
| **II—Direct underlying events** | Inadequate design, inadequate training, physiological conditions |
| **III—Indirect underlying events** | Inadequate surveillance of operation, insufficient standards |

To illustrate the NTSB accident coding system, consider a maintenance-related accident from March 2007, when a Bell 206L-1 on an air-taxi mission lost engine power during cruise. The investigation findings blamed the accident on incorrect installation of the engine fuel line fitting by maintenance personnel (NTSB ID: DFW06FA083). Table 4 provides a breakdown of the corresponding subject codes and modifiers used to explain this accident in the database.

Table 4: Illustration of NTSB Accident Coding in 1982–2008

| Numeric Code | NTSB Classification | Description |
|---|---|---|
| 24111 | Subject Code | Maintenance, Installation |
| 3109 | Modifier | Improper |
| 4108 | Personnel Modifier | Other maintenance personnel |

NTSB investigators place occurrences in a sequence leading up to the accident. They use three digit codes ranging from “*100: Abrupt Maneuver*” to “*430: Miscellaneous/Other*”.

### 3.1.2 Current System (2008–Present)

In 2008, the NTSB began recording accidents using a new coding system. In place of the subject codes, the NTSB introduced ten digit findings codes, which ranges from “*01000000XX: Aircraft handling/service*” to “*05000000 XX: Not determined*”. The last two digits “**XX**” represent the modifier codes.

For example, consider an accident involving a Robinson R-44 II in June 2012. During a cherry-drying operation near Wenatchee, WA, the pilot maneuvered close to power lines (NTSB ID: WPR12LA259). The main rotor impacted the power lines, and the helicopter crashed into the trees. The pilot was seriously injured and the helicopter sustained substantial damage. The pilot's failure to maintain clearance from the power lines was one of the causes for the accident; given by the findings code *0106201220*. Table 5 shows the breakdown of the findings code. To facilitate clarity, we will refer to findings codes as subject codes in the remainder of this document.

Table 5: Illustration of NTSB Breakdown of Findings Code in 2008–Present

| **Findings Code** | **NTSB Classification** | **Description** |
|---|---|---|
| ***01***06201220 | Category | Aircraft |
| 01***06***201220 | Subcategory | Operation/performance/capability |
| 0106***20***1220 | Section | Performance/control parameters |
| 010620***12***20 | Subsection | Altitude |
| 01062012***20*** | Modifier | Not attained/maintained |

In the post-2008 system, the NTSB replaced the three-digit occurrence codes with six-digit codes. The first three digits correspond to the phase of flight, and the last three digits represent an "event". Consider for example the code *500240,* where the first three digits (***500****240*) indicate approach phase of flight, while the last three digits (*500****240***) represent loss of control inflight. To facilitate ease of understanding and continuity with the old system, I will refer to the last three digits as occurrences for the remainder of this thesis.

## 3.2 Issues with Accident Data

Multiple data issues should be borne in mind while analyzing NTSB accident data, and arriving at conclusions about accident causation. I highlight here some of the key issues associated with the data. These issues include incomplete or inconsistent data entries in the database, lack of information about the current coding system, subjectivity in probable cause determination, and inconsistency in published accident narratives. I highlight relevant data issues while presenting analysis results.

### 3.2.1 Lack of Consistency in Data Entries

Inconsistent entry of data fields is one of the major issues in the accident database. The absence of information in many cases impedes accident trend analysis. Consider for example aircraft “airframe hours”. Airframe hours help estimate the amount of time an aircraft has been in service[16]. Consistent reporting of airframe hours could potentially help correlate airframe-related failures and flying time[17]. Unfortunately, the NTSB does not report airframe hours in each accident. Potential reasons including inaccessible maintenance records and/or pilot logs.

### 3.2.2 Changes in Accident Recording System

The NTSB changed its accident recording system twice: first in 1982, followed by the transition to the current system in 2008. While the transition to the current coding system provides additional capabilities to the analyst (e.g., creation of a CFIT occurrence), it also

[16] Some of the common methods of estimating airframe hours include: (1) using pilot log books to calculate the amount of flying time accrued by the aircraft; (2) referring to maintenance logs, which base their information on tachometer readings and pilot logs; and in some cases, (3) using an “air hobbes” that activates only when the aircraft is off the ground.
[17] Note that since the NTSB does not record the year of manufacture of an aircraft, it is generally difficult to determine the age of the aircraft at the time of the accident.

presents some challenges. One of the issues involves the deletion of fields from the previous version of the database. For example, in the old system the NTSB represented US-registered aircraft by the *USUS* code. This code is no longer used in the current system—making it challenging to identify aircraft that are registered in the US.

Another challenge with the current system involves the information lost during the transition away from five-digit subject codes to 10-digit findings codes. The absence of a "map" (correspondence between codes in the old and new system) creates a "gap" or discontinuity while reporting results. During my review of multiple historical accident studies, I noticed that many studies restricted their analysis to either pre-2008 accidents or considered only accidents post-2008. This problem (absence of a map) is further exacerbated by the absence of a coding manual for the new system[18].

### 3.2.3 Subjectivity in Recording Accident Details

It is worthwhile to take a moment here to consider the levels of information available to investigators and analysts, as shown in Figure 12. First, the accident itself has all the requisite detail, by the very fact that it occurred. Second, a smaller subset of information is available to investigators, because we cannot possibly know every single detail of the accident. Third, it is possible that the investigators do not obtain all the theoretically available information about the accident. For example, a witness may know something about the accident, but that witness might not be found and questioned. At the same time, the witness is putting their own interpretation on what they experienced, further

[18] Unlike the pre-2008 system, the NTSB does not provide a detailed manual of how accidents are recorded in the current system. Information for the post-2008 system can be found in the dictionary table in downloadable NTSB database. This table provides brief descriptions of the different findings and occurrence codes.

obfuscating the true nature of the accident. Fourth, the investigators may not record every piece of information in their narrative, while simultaneously putting their interpretation on the findings. And finally, the investigators might not code all the information into the database.

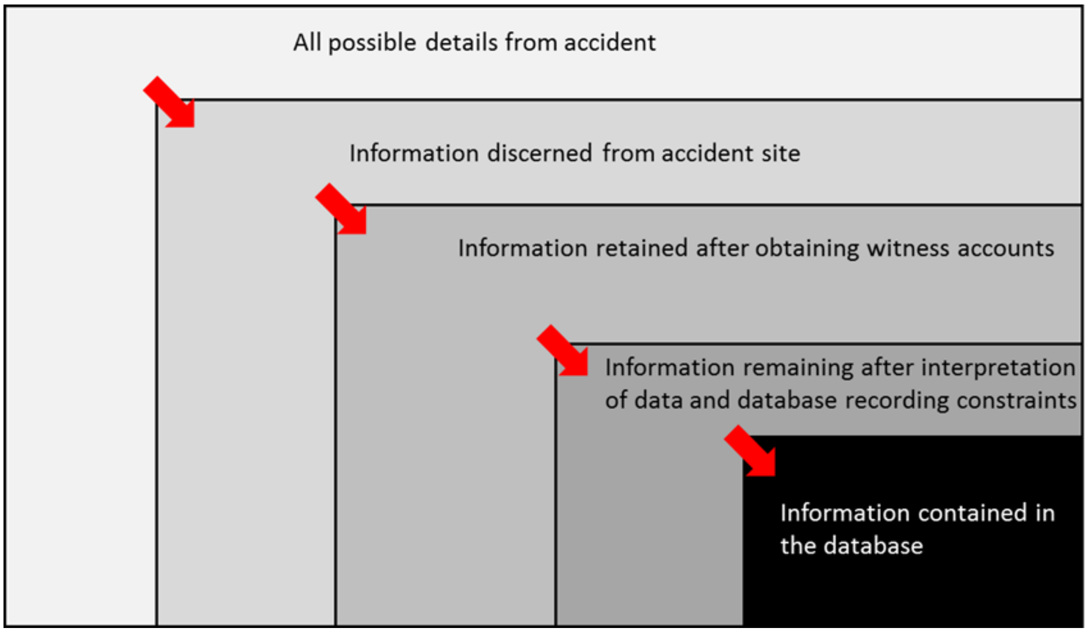


Figure 12: Levels of information available to accident investigators and safety analysts.

### 3.2.4 Inconsistency in Accident Narratives

Generally, each accident is accompanied by a detailed factual report and a synopsis or brief report. The brief reports contain information on the occurrences, subject codes and modifiers, and the causes and contributing factors to accidents. They also include a probable cause statement that summarizes the NTSB's accident findings in a couple of lines. In contrast, the factual reports include a history of flight narrative that gives the reader some background on the events leading up to the accident. The factual reports also include information on personnel (e.g., age, experience, medical certificate, and ratings held by pilots); aircraft (e.g., owners, serial numbers, powerplant models, and airframe hours); meteorological information (e.g., wind, ceiling); airport or landing site; and wreckage and impact information. In addition to the narratives, they include details on the nature of operations (e.g., personal use, aerial application), levels of damage (e.g., destroyed, substantial), and names of investigation personnel. These accident reports could potentially yield valuable insight into accidents; however, not all accidents have factual reports, and for those that do, the level of details varies significantly[19].

Table 6: Summary Statistics of Factual and Brief Accident Reports

| **Type of Report** | **Pre-2008 (Accident Count = 5198)[20]** | | | **Post-2008 (Accident Count = 982)** | | |
|---|---|---|---|---|---|---|
| | **Count** | **Mean** | **SD** | **Count** | **Mean** | **SD** |
| Factual | 2769 | 730 | 904 | 982 | 806 | 1071 |
| Brief | 5198 | 128 | 90 | 964 | 200 | 157 |

Table 6 summarizes the availability of factual reports in the database. The count indicates the number of accidents that had factual reports with a "non-zero" word count. Only about half (53.3%) of pre-2008 accidents had factual reports with information in them. The large standard deviation (904.3) suggests varying levels of detail in the reports. It is encouraging to note that every accident in 1982–2008 had a brief report; providing potential learning opportunities. In contrast to 1982–2008, all 982 helicopter accidents post-2008 had factual reports. These reports also had large variation in their level of detail. Comparing the average factual report lengths for pre and post-2008 accident (t-test at significance level 5%) reveals a statistically significant difference. However, further investigation of the

[19] The interested reader is directed to Leveson (2001, pp. 13–18) for a comprehensive discussion regarding the use of accident reports and potential limitations.
[20] Note that there were 43 midair collision that involved 63 helicopters. Therefore, the total number of (helicopters in) accidents is 5218 for 1982–2008.

effect size[21] reveals that difference between the mean report lengths is marginal. In other words, the average lengths of the reports did not change over the two time periods.

## 3.3 Features of Accident Dataset

The accident dataset analyzed in this thesis consist of all civil helicopter accidents that occurred in the US in 1982–2015. The dataset contains 6200 helicopter accidents—5218 accidents were recorded (by the NTSB) under the old system (1982–2008), while the remaining 982 were recorded under the current system (2008–present). Fatal accidents accounted for 16.2% (1005 out of 6200) accidents.

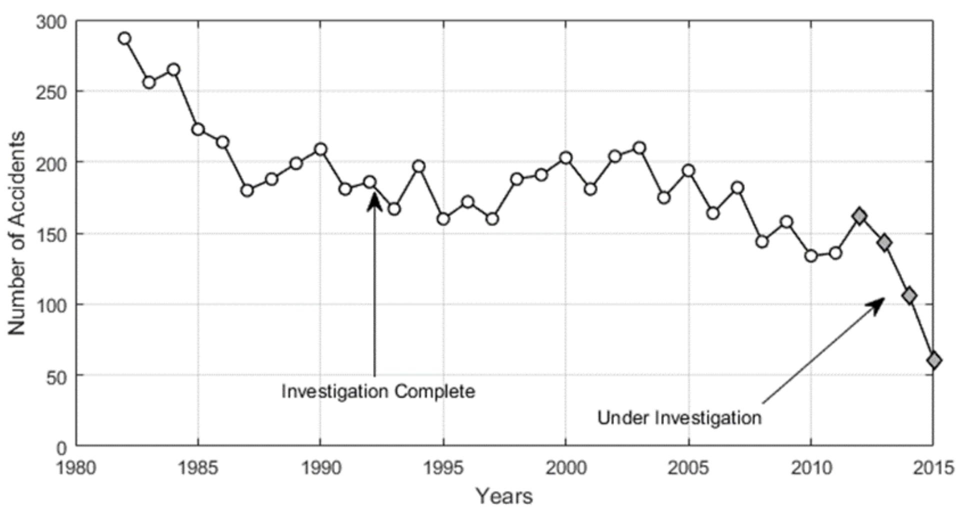


Figure 13: Helicopter accident trends between 1982 and 2015. The grey markers represent the years that still have ongoing accident investigations.

Figure 13 shows a decreasing trend for the number of helicopter accidents each year. The drop in the number of accidents after 2013 is primarily due to the number of ongoing accident investigations. As expected, the number of accidents under investigation is higher for more recent years (Table 7).

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[21] Comparing the means using a *t*-test at a 5% significance level suggests a statistically significant difference. The Cohen's *d* value is ~0.08—indicating that the difference between the means is trivial.

Table 7: Accident Year and Number under Investigation

| **Year** | **Accidents still under investigation (% of total accidents that year)** |
|---|---|
| 2012 | 1 (0.6%) |
| 2013 | 3 (2.0%) |
| 2014 | 36 (25.3%) |
| 2015 | 69 (53.1%) |

## 3.4 Occurrence Chains: Do They Tell the Full Story?

This section presents a method to identify high-risk occurrence chains (or sequence of occurrences) using historical accident data. This method uses a frequentist approach to calculate the presence of various occurrence chains in helicopter accidents that occurred in the US between 1982 and 2008. The chains are ranked for different injury severity levels and mission types.

### 3.4.1 Approach to Identifying High Risk Occurrence Chains

Risk is essentially a combination of the probability and consequences of a given set of events. We usually refer to risk by one or a combination of these dimensions. For example, we refer to the chance of winning a lottery (probability), the potential areas impacted by a hurricane (consequences), or the expected number of motor vehicle accident fatalities in a year (probability times consequence).

In the case of accidents, the consequences are always negative; that is, there is no “upside” risk, as there may be in, for example, financial transactions. For accidents, we usually interpret consequences in terms of loss of life, injury, and loss of property. We may, for example, refer to the number of fatalities associated with rotorcraft firefighting efforts in a given year. When considering populations, or accidents during a particular time period or in a particular area, we also interpret consequences using simple or normalized counts. For example, we may track trends in the number of accidents per year in a particular region, and we might normalize this number by flight hours. It is important to consider these different dimensions of risk when developing accident reduction measures. For example, consideration of fatalities resulted in commercial aircraft designers creating aircraft with measures to increase survivability in a crash (e.g., fireproof and fire resistant cabin materials). Conversely, reducing the raw number of accidents is also important—the public would likely stop using commercial aviation if there were frequent small accidents, even if they did not result in injuries. Accidents that seem less significant from an injury or loss perspective may also provide insights into potentially more serious accidents. This perspective is particularly relevant to general aviation, where fatal accidents often involve so much damage that little physical evidence can be found (these aircraft rarely have "black boxes").

Here, I show how occurrence chains corresponding to different perspectives on risk can be identified. In particular, I identify the occurrence chains that most often result in accidents, and the occurrence chains that most often result in accidents of a particular severity (e.g., which chains are most likely to result in fatal accidents).

The analysis approach consists of three steps, as described next.

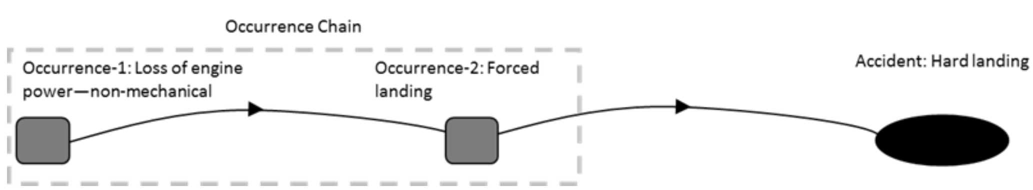


Figure 14: Directed network between occurrence chain and accidents.

First, I identify the occurrence chains corresponding to the accidents. My example from Table 4 illustrates the process, as shown in Figure 14. As mentioned in Section 3.1, the

NTSB accident reports place each occurrence in a sequence leading up to the accident. In this thesis, I designate the final node as the accident. In this case, I therefore have a two-node occurrence chain (Loss of engine power—non- mechanical, Forced landing) followed by a hard landing accident.

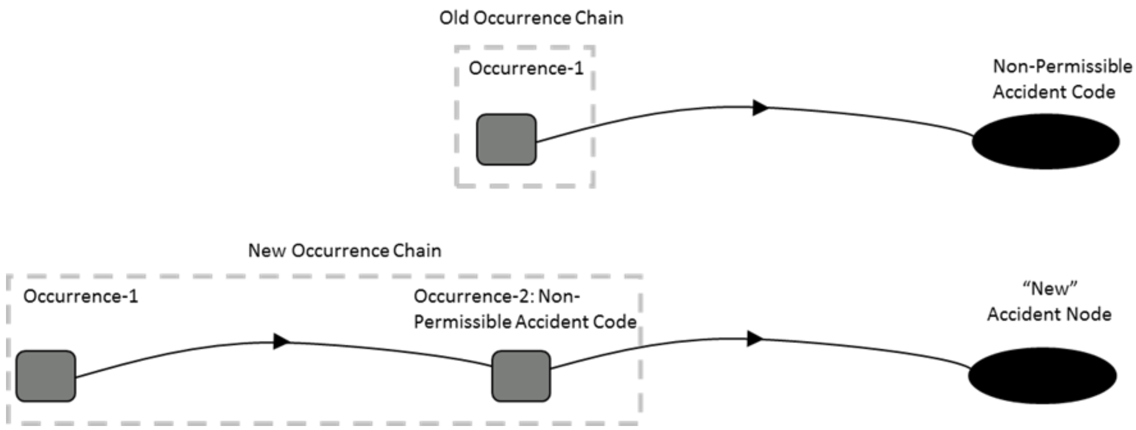


Figure 15: The non-permissible accident code is introduced into the occurrence chain and a "new" accident node is introduced.

In some accidents, the NTSB reports "non-intuitive" final occurrences (e.g., loss of control, loss of engine power). For example, when accident reports suggest that LOC was the final occurrence, I know that the accident ultimately must have involved the helicopter crashing into the ground, water, or other object following the loss of control. Thus the NTSB coding must be missing the final occurrence node. I term these occurrence codes that must have an ensuing node, though it is not documented, as "non-permissible accident codes". Tables 284 and 285 in Appendix F show the full list of occurrences that I consider non-permissible and permissible accident codes. After identifying the accidents with non-permissible terminating codes, I place the non-permissible occurrence in the chain and introduce a "New" accident node, as shown in Figure 15. So, for example, if an accident had "250: Loss of control" as the terminating occurrence, then the chain is re-coded as:

"250: Loss of control" + *"New Accident Node"*

In some accidents, only a single occurrence is recorded by the NTSB. One such accident occurred in April 1994 during an air-medical mission near Bluefield VA (NTSB ID: BFO94FA071). The pilot of a Bell 214 did not execute the correct instrument approach in IMC conditions (rain, fog, and low ceiling). The subsequent *collision with terrain* (230) resulted in four fatalities. The investigators added that better instructions from the ATC personnel could have prevented the accident. Here, since "*230: Inflight collision with terrain/water*" is a permissible terminating occurrence as well as the only occurrence recorded in the database, I record this occurrence chain as "*230**S**: Inflight collision with terrain/water"*. The suffix **S** indicates that chain had a single occurrence and was the terminating occurrence (or accident node).

After identifying the occurrence chains, I calculate the presence (cf. Sorenson and Marais, 2015) of $occurrence\ chain_j$ as number of times each chain *j* appears in different types of accidents (e.g., fatal, non-fatal), normalized by the total number of (fatal, non-fatal) accidents:

$$\begin{gathered} presence\left(Occ\ Chain_j \middle| Fatal\ Accident\right) \\ = \frac{\sum_{i=1}^{n_{fatal\ accidents}} TRUE\left(Occ\ Chain_j \text{ AND } Fatal\ Accident_i\right)}{\#Fatal\ Accidents} \\ presence\left(Occ\ Chain_j \middle| Non\ Fatal\ Accident\right) \\ = \frac{\sum_{i=1}^{n_{non\ fatal\ accidents}} TRUE\left(Occ\ Chain_j \text{ AND } Non\ Fatal\ Accident_i\right)}{\#Non\ Fatal\ Accidents} \end{gathered} \tag{1}$$

For example, the single node "*250: Loss of Control inflight*" chain appears in 121 out of the 845 fatal accidents, thus its presence in fatal helicopter accidents is 14.3%. Note that midair collision accidents involve more than one aircraft that can have the same or different sequences of occurrences leading up to the collision (and after).

### 3.4.2 Occurrence Chain Statistics

This section provides key occurrence chain statistics. First, I identify the top occurrence chains in accidents overall. Then, I determine the top chains in fatal accidents, and compare their presence in accidents that were non-fatal. Finally, I compare the presence of the top chains overall across different mission types.

#### 3.4.2.1 Old System (1982–2008)

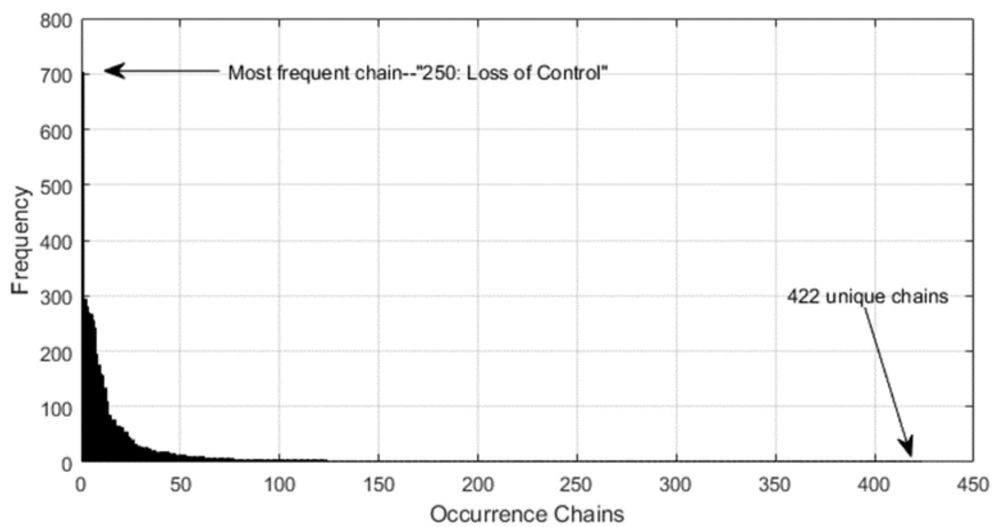


Figure 16: Distribution of occurrence chains in 1982–2008. “250: Loss of control” was the most frequent chain; associated with 13.5% of helicopter accidents.

Figure 16 shows the frequency distribution of occurrence chains for helicopter accidents in 1982–2008. These accidents were associated with 422 different occurrence chains, where the top 10 chains accounted for over half the accidents (54.6% of accidents). 54.6% of the accidents had only one occurrence, 36.4% of the accidents had two occurrences, and 7.2% of the accidents had three or more occurrences. Accidents had an average chain length of 1.55 (with SD = 0.67).

Table 8: Presence of the Top-Five Occurrence Chains in All Accidents

| **First Occurrence** | **Second Occurrence** | **Presence in Accidents** |
|---|---|---|
| Loss of control-inflight (250) | - | 13.5% |
| Loss of engine power (350) | Forced landing (180) | 5.7% |
| Loss of engine power-non-mechanical (353) | Forced landing (180) | 5.4% |
| Inflight collision with terrain/water (230S) | - | 5.2% |
| Inflight collision with object (220) | - | 5.1% |

Table 8 compares the presence of the top five occurrence chains in all US helicopter accidents in 1982–2008. The presence of each occurrence chain is calculated using Eq. 1. "*250: Loss of control inflight*" (LOC) was the top occurrence chain, accounting for 13.5% of all helicopter accidents. The high frequency of the LOC chain may reflect a lack of detail in many investigations, since we would expect that LOC would be induced by some prior event (which may not be known).

Note the occurrence chain "*230**S**: Inflight collision with terrain/water*", where the 'S' signifies that this chain was the sole recorded occurrence in the accident. 5.2% of accidents result from this chain, but unfortunately, the NTSB reports do not indicate what happened before the collision. Again, as with LOC, I assume that in each accident there must have been some instigating factor that was not captured by the investigation.

#### 3.4.2.2 Injury-Specific Occurrence Chain Ranking

Next, I identify the top occurrence chains in fatal accidents and compare their presence in non-fatal outcomes. An accident is fatal if any injury sustained results in death within 30 days of the accident (NTSB, 1998). I group accidents that had serious, minor, or no injuries as "non-fatal" accidents.

Table 9: Comparison of the Presence of Top Occurrence Chains in Fatal and Non-Fatal Accidents

| **Occurrence Chain** | | **Presence in Accidents** | |
|---|---|---|---|
| **First Occurrence** | **Second Occurrence** | **Fatal** | **Non-fatal** |
| Loss of control inflight (250) | - | 14.3% | 13.4% |
| Inflight collision with object (220) | - | 10.0% | 4.2% |
| Inflight collision with terrain/water (230S) | - | 9.0% | 4.4% |
| Airframe/system/component failure (130) | Loss of control inflight (250) | 6.4% | 1.8% |
| Inflight encounter with weather (240) | - | 6.4% | 1.2% |

Table 9 compares the presence of the top five fatal occurrence chains in fatal and non-fatal accidents. Three of the top five chains overall (Table 6) are among the top five for fatal accidents; i.e., LOC, collision with terrain/water, and inflight collision with object. "*240: Inflight encounter with weather*" enters the top five chains for fatal accidents, highlighting the tendency of flights into poor weather to result in fatal outcomes.

The loss of control chain appeared most frequently in both fatal and non-fatal accidents. Unfortunately, the high presence of the single node LOC chain suggests that investigators had limited information about the occurrences that preceded LOC. In some cases, the investigators were able to establish the precursor to loss of control. One such example is the chain "*130-250: Airframe/system/component failure* followed by *LOC*", which appeared in 6.4% of fatal accidents. System failures, particularly flight control cables and control surfaces, made it difficult (if not impossible) for the pilot to control the aircraft.

Often, helicopter mission require operation in proximity to objects/terrain. Unsurprisingly, "*220: Inflight collision with object*" and "*230S: Inflight collision with terrain/water*" were among the top occurrence chains for fatal accidents. Similar to the LOC chain, the single node collision with object/terrain chains do not provide any insight into the events that preceded them.

#### 3.4.2.3 Operation-Specific Occurrence Chain Statistics

The NTSB defines 34 types of operation, of which 20 are reported in the context of helicopter accidents. When the type of activity being carried out at the time of the accident is unclear, the NTSB assigns the *UNK* code[22]. Table 10 shows the five types of operation that most frequently resulted in accidents between 1982 and 2008.

Table 10: Top-Five Operation Categories Involved in Accidents

| **Type of Operation** | **Description** | **Accidents** |
|---|---|---|
| PERS | Personal use | 1048 (20.2%) |
| INST | Instructional flight | 868 (16.7%) |
| AAPL | Aerial application | 631 (12.1%) |
| UNK | Unknown | 627 (12.0%) |
| OWRK | Other work use | 386 (7.4%) |

Personal use missions accounted for the largest proportion of accidents in 1982–2008. Accidents involving instructional flights were the second most frequent, accounting for 16.7% of all accidents. These accidents generally involved solo-flights by students, in some cases accompanied by a Certified Flight Instructor (CFI). Flight training also involved simulated emergency scenarios to better prepare pilots in the event of an emergency during a non-training flight. However, the pilot's (or CFI's) inability to recover from a simulated emergency often resulted in accidents. DeVoogt (2007) points out the paradoxical nature

[22] In certain accidents, the NTSB coded the mission type as "unknown" or "other work" while also indicating that the accident was either an "air medical" or "site seeing" mission. Using this information, I identified 157 site seeing accidents and 199 air medical accidents.

of helicopter training—that is, the frequency of accidents during simulated emergencies is higher than the frequency of these emergencies occurring during non-instructional flights. He also suggests that student pilots are exposed to high levels of risk during training by practicing for emergencies that have rarely resulted in accidents during non-instructional missions.

Aerial application missions generally involve agricultural operations such as application of pesticides or plant fertilizers. 12.1% of the accidents occurred during this mission. Collision with objects (e.g., wire strikes) and loss of engine power due fuel starvation/contamination were among the top causes for aerial application accidents. The NTSB classified 12% of the accidents under the "unknown" mission category[23]. The "other work" mission category, which accounted for 7.9% of the accidents, involved various flights including cattle herding, blow-drying of plants, and transportation of workers to worksites.

Table 11: Comparison of the Presence of Occurrence Chains for different Mission Types

| **Occurrence Chain** | | **Percentage of Accidents** | | | | |
|---|---|---|---|---|---|---|
| **First Occurrence** | **Second Occurrence** | **PERS** | **INST** | **AAPL** | **UNK** | **OWRK** |
| Loss of control-inflight (250) | - | 15.9% | 16.1% | 10.3% | 11.5% | 11.4% |
| Loss of engine power (350) | Forced landing (180) | 7.0% | 3.5% | 6.5% | 5.7% | 4.7% |
| Loss of engine power-non-mechanical (353) | Forced landing (180) | 5.6% | 2.0% | 10.5% | 4.6% | 8.0% |
| Inflight collision with terrain/water (230**S**) | - | 5.4% | 6.3% | - | 5..9% | 2.1% |
| Inflight collision with object (220) | - | 4.5% | 1.8% | 11.4% | 2.7% | 7.0% |

[23] In the NTSB database, 1.7% of the accidents had "blank" fields for mission type. For purposes of clarity, I do not combine these "blank" mission type accidents with those that the NTSB designated as unknown.

The LOC chain has the highest presence in accidents that involved personal flights and instructional activities (Table 11). As stated earlier in this section, the frequent citing of the single node chain provides little insight into understanding the causes for loss of control. Likely reasons for the frequent use of the single node chain are: (1) Lack of information available to the investigator from the accident site and witness interviews (ref. Figure 12); and (2) Lack of depth in accident investigation.

The "*200**S**: Hard landing*" chain does not appear in the top five most frequent chains. However, it has the second highest presence in instructional flying accidents; appearing in 15.7% of instructional accidents. The presence of the LOC chain is almost the same (16.1%), but it tends to result in more fatalities and serious injuries. Many hard landing accidents involving student pilots happened during the landing or hover-to-landing phases. Student pilots are usually relatively inexperienced in judging distances and monitoring RPM.

*Inflight collision with an object* (220) is the top occurrence chain for accidents during aerial application missions. Wire strikes, agricultural operations, and main and tail rotor strikes were the dominant characteristics of collision with object accidents. Also, the probability of "*353-180: Loss of engine power-non-mechanical* followed by a *forced landing*" is the highest for these operations, suggesting negligence during preflight checks for common non-mechanical triggers such as fuel and oil levels.

3.4.2.4 Comparison of Pre and Post-2008 Occurrence Chains

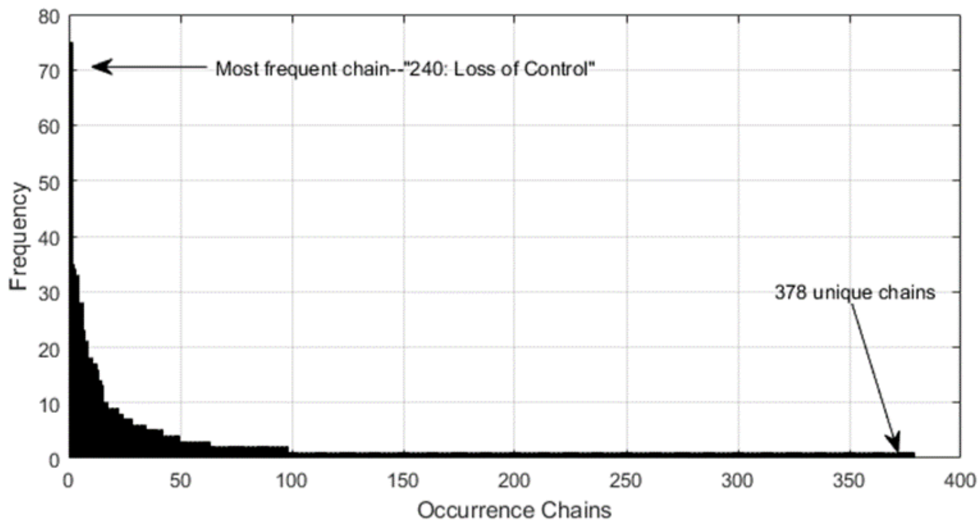


Figure 17: Distribution of occurrence chains in 2008–2015. "240: Loss of control" was the most frequent chain; associated with 7.6% of helicopter accidents.

The frequency distribution of occurrence chains in 2008–2015 (Figure 17) is similar to that of 1982–2008 (see Figure 16). Accidents in 2008–2015 were associated with 378 different occurrence chains. 51.7% of the accidents had only one occurrence, 31.7% of the accidents had two occurrences, and 16.6% of the accidents had three or more occurrences. In contrast to the old system (where the top 10 chains accounted for over half the accidents), the top 10 chains in the current system accounted for only 31.9% of the accidents. The reduced proportion of accidents could be attributed to multiple reasons including: (1) Investigators leveraged the greater variety of occurrence codes in the current system (98 compared to 54 in the old system) to better represent accidents; (2) Greater variety of accidents; or (3) just that the sample size is smaller (fewer accidents) and hence the proportion estimate has not converged to the true proportion[24].

[24]Owing to the lower accident count, there might be fewer accidents associated with a particular occurrence chain ***j***. As more accidents occur (and are recorded by the NTSB in current system), the frequency of this chain ***j*** might increase—thus increasing the proportion of accidents associated with the chain.

Table 12: Comparison of Occurrence Chains Pre and Post-2008

| Information | Old System (1982–2008) | Current System (2008–2015) |
|---|---|---|
| Number of accidents | 5218 | 982 |
| Number of Occurrences | 54 | 98 |
| Number of occurrence chains | 422 | 378 |
| Top occurrence chain (% presence) | 250: Loss of control inflight (13.5%) | 240: Loss of control inflight (7.6%) |
| Average chain length (and SD) | 1.55 (0.67) | 1.73 (0.95) |
| Number of single node chains | 51 | 89 |
| Accidents per occurrence chain | 12.3 | 2.6 |

Table 12 compares key information for occurrence chains that were recorded under the old and current systems. Investigators frequently attributed accidents to *Inflight loss of control*—the top occurrence chain in accidents recorded under the old and current systems. Unfortunately, the continued use of the single node LOC chain does not help us (safety analysts) better understand LOC accident causation. In fact, the proportion of single node chains increased in the current system (23.5% compared to 12.1% in the old system). A comparison of the chain lengths reveals a statistically significant (confidence level of 5%) higher average for chains in the current system. The Cohnen's d value is 0.24, indicating that the size of the difference between the means is moderate.

The current system also introduced over 40 new occurrences to better represent accidents. One such example is the *controlled flight into terrain* (CFIT) and non-CFIT occurrences. The old system did not explicitly mention CFIT in the coding system, making it difficult for the analyst to identify such accidents. In the subsequent chapter, I will present an approach to identifying CFIT accidents using the old system.

The last row of Table 10 presents the accidents per occurrence chain metric. This metric captures the average "usage" of an occurrence chain to capture accidents. In 2008–2015, each occurrence chain captures only 2.6 accidents—almost five times less than in 1982–2008. The lower number of accidents per occurrence chain in the current system suggests that a greater variety of chains is used by investigators. Tracking this metric, as more accidents are recorded, could potentially provide a better insight into: (1) the variety of occurrence chains used by investigators to capture accidents; and (2) the different accident trajectories.

### 3.4.3 Lesson Learned from Occurrence Chain Analysis

I began this chapter by asking the following question:

*Can we learn more about GA accident causation by counting and comparing these occurrence chains?*

The answer is yes, we can learn a little more than just a root cause analysis. In Section 3.4, I demonstrated the occurrence chain approach to identifying accident "stories". My analysis showed that accident stories tended to be short; that is, over 82% of the accidents in 1982–2015 had a maximum of two nodes. I ranked occurrence chains based on their presence in accidents. The high presence of the single node loss of control (LOC) chain, while highlighting the well-known tendency for pilots to lose control, also suggests a lack of information available to investigators to reconstruct the accident story.

The occurrence chain approach also helps with comparing accident stories across different injury severity levels. Take for instance the single node hard landing chain (200**S**)—it has the highest presence in instructional flight accidents and generally resulted in minor or no injuries to the occupants. Occurrence chains also help highlight mission-specific safety issues. For example, in 2008–2015, "*220: Low altitude operations*" chain (not present in the pre-2008 system) had the highest presence in aerial application accidents. This chain highlights the tendency for pilots during aerial application missions to fly in proximity to the ground.

While this approach helps us think beyond a single root cause by identifying the most risky event sequences, it does not provide a complete picture of an accident. I discuss some of the key issues with the occurrence chain technique in the remainder of this section.

Like with any chain of events model, this approach also suffers from backward chain propagation, where the assignment of an initiating event can be arbitrary as it is dependent on the stopping point when going backward in the event chain. To illustrate this point, recall the earlier example involving a fatal crash that occurred in poor weather condition (NTSB ID: BFO94FA071). Inflight collision with terrain/water (230) was the only occurrence used in this accident. However, one could ask why this accident was not coded as "*240–230: Inflight encounter with weather* followed by an *inflight collision with terrain/water*". The occurrence chain technique is dependent on an investigator's interpretation of the sequence of events that led to an accident.

While the low average chain length might suggest lack of information available in the accident, the occurrence chain technique does not leverage all the information available in the subject codes and modifiers. Often, subject codes provide vital information to understanding the reasons behind an occurrence. For example, many LOC accidents are associated with the subject-modifier combination "*poor inflight planning/decision making*".

Here, I can say that the pilot's poor decision was one of the causes for LOC. In addition to not using subject codes, the large variety of occurrence chains (422 in the old system and 378 in the current system) makes it difficult to propose any intervention strategies.

As mentioned in Chapter 2, several researchers have analyzed NTSB accident data to identify the causes for GA accidents. Some research looked exclusively at occurrences (or occurrence chains) to explain accident causation. Other GA accident literature focuses on the subject codes that are designated as "causes" or "factors" by the NTSB. In an effort to potentially better understand GA accident causation, in the next chapter, I propose a state-based accident model.

# CHAPTER 4. A STATE-BASED AVIATION ACCIDENT MODEL

One of the key objectives of accident investigations is to learn how to prevent future accidents. In Chapter 3, I presented the NTSB's accident recording system and analyzed the top occurrence chains in helicopter accidents. The NTSB accident coding system lends itself to a chain of events model of accidents. Such models have several limitations (Leveson, 2001), in particular, not all aspects of an accident can be viewed as "events" (e.g., poor training is a continuing condition, or state, rather than an event). In this chapter, I propose a state-based accident modeling approach to potentially better understand GA accident causation.

Section 4.1 reviews the fundamental elements of a state-based approach. In Section 4.2, I provide the definitions for a system, nominal state, and hazardous state using illustrative helicopter accident examples. Section 4.3 describes the dictionary of hazardous states and trigger events from the NTSB accident database. Section 4.4 details how I use the accident data to build the "grammar" that links hazardous states to trigger events.

## 4.1 Basic Elements of State-based Approach

Before discussing the details of how I use NTSB data to build the accident model, it is important to understand the basic elements of the model. Figure 18 shows a state-based representation of a notional system.

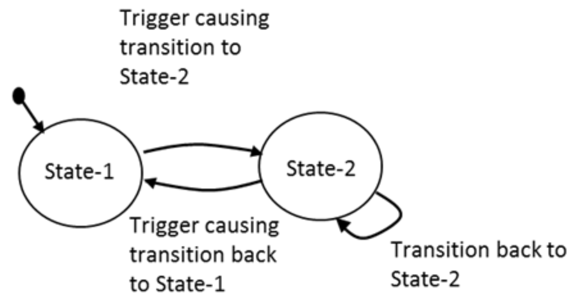


Figure 18: State-based representation of a simple notional system. The nodes represent the different states of the system, the links with arrows represent the transitions. Triggers cause the system to transition from one state to another (or remain in the same state).

The basic elements of the state-based model are: (1) states; and (2) triggers.

**State:** Segments of time wherein a system exhibits a particular behavior. The nodes in Figure 1 represent the two possible states of the notional system. The link with the black node points to the "default" or "start" state of the system. A system must be in one and only one state at any given point of time.

**Triggers:** Occur at precise instants of time and cause a system to transition between states or remain in the same state. Triggers may be deterministic or stochastic. In some cases, the amount of time spent in a state can cause the system to move to a new state (e.g., the time spent flying through instrument meteorological or IMC conditions can trigger a spatial disorientation state). If the system remains in a state beyond a specified time bound, it triggers a time-out, which transitions the system to a new state.

## 4.2 Definitions of System and States in the Accident Model

For the state-based aircraft accident model, the helicopter and the pilot(s) operating the helicopter constitute the system. I graphically represent the two constituents of the system as two halves of a circle—the top half representing the state of the pilot(s) operating the aircraft, and the bottom half representing the state of the aircraft (Figure 19).

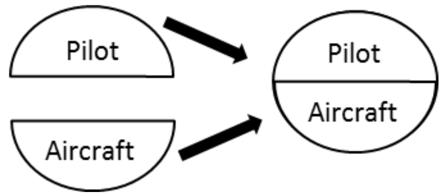


Figure 19: Building the system from its constituent parts. The top half of the circle represents the state of the pilots operating the aircraft, while the bottom half represents the states of aircraft.

The state[25] of a system at any instant of time is given by:

$$x(t) = \begin{bmatrix} \text{Pilot} \\ \text{Aircraft} \end{bmatrix} \tag{2}$$

where, $\boldsymbol{x(t)}$ represents the state of the system at any given instant of time $\boldsymbol{t}$.

A **nominal state** for the system is defined as a state of system operation that is accepted as safe by society. The system is said to be in a nominal state if both constituents of the system (pilot and aircraft) are in a nominal state, as shown by the green circle in Figure 20.


Figure 20: Illustration of the nominal state for the system.

Operating the system in a nominal state does not imply that the system is absolutely (100%) safe[26]. It just means that the system is in a less unsafe state compared to a hazardous state. A **hazardous state** for the system can be defined as "A state of system operation that is less safe compared to the nominal state (i.e., off-nominal operation)". The state immediately preceding an accident or incident must be a hazardous state—the system

[25] The state-based approach used in this thesis does not attempt to model the dynamics of the entire system. Here, I leverage historical accident data to model the different states of a system (pilot and aircraft) during operation, and to identify triggers that cause the system to transition between states.

[26] While in reality there is no system that can be 100% safe, for completeness, I state that, a system that is 100% safe cannot transition to a hazardous state; i.e., it always transitions back to the 100% safe state.

cannot transition directly from a nominal to an accident/incident state. The system is said to be in a hazardous state if it is in one of the following scenarios:

a) Pilot is in a hazardous state.

b) Aircraft is in a hazardous state.

c) Both pilot and aircraft are in a hazardous state.

Figure 21 illustrates the three scenarios (a, b, and c) in which the system is in a hazardous state.

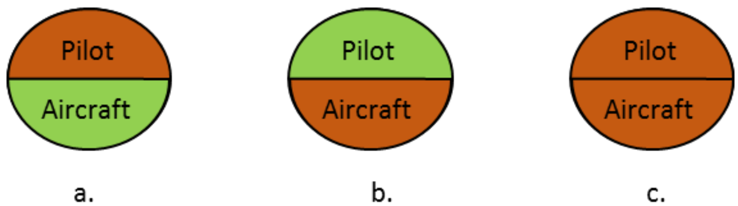


Figure 21: Illustration of the three possible scenarios in which a system is said to be in a hazardous state. Scenario (a) happens when the pilot is in a hazardous state (e.g., physical impairment due to prescription medication), scenario (b) occurrs when the aircraft is in a hazardous state (e.g,, poorly maintained aircraft or loss of control state), and scenario (c) happens when both (a) and (b) occur.

The mathematical representation of a system's hazardous state (based on the source of the hazard) are given by:

$$x_{haz}(t) = \begin{bmatrix} \text{Pilot}_{\text{haz}} \\ \text{Aircraft} \end{bmatrix} \tag{3}$$

$$x_{haz}(t) = \begin{bmatrix} \text{Pilot} \\ \text{Aircraft}_{\text{haz}} \end{bmatrix} \tag{4}$$

$$x_{haz}(t) = \begin{bmatrix} \text{Pilot}_{\text{haz}} \\ \text{Aircraft}_{\text{haz}} \end{bmatrix} \tag{5}$$

where, $\text{x}_{\text{haz}}(\text{t})$ indicates that the system is in a hazardous state, $\text{Pilot}_{\text{haz}}$ indicates that the pilot is the source of the hazard, and $\text{Aircraft}_{\text{haz}}$ indicates that the aircraft is the source of the hazard.

The system can start a mission in either the nominal flight state or a hazardous state, transition through a set of hazardous states during flight, and end in one of three possible end states: (1) accident; (2) incident; or (3) safe landing.

To facilitate a better understanding of the different states and triggers, I consider examples of accidents under the following categories:

1. A flight that began with the system in a hazardous state due to poor aircraft maintenance.
2. A flight that began with the system in a hazardous state due to pilot impairment.
3. A flight that began with the system in a nominal state.

**Preflight Mechanical Issue due to Improper Maintenance (NTSB ID: DEN84FA207)**

In a July 1984 accident near Englewood, CO, a Bell 206B experienced an on-board system failure and subsequent loss of control before colliding with terrain. The resulting accident killed both the pilot and the passenger. The NTSB cited incorrect maintenance installation as one of the causes for this accident.

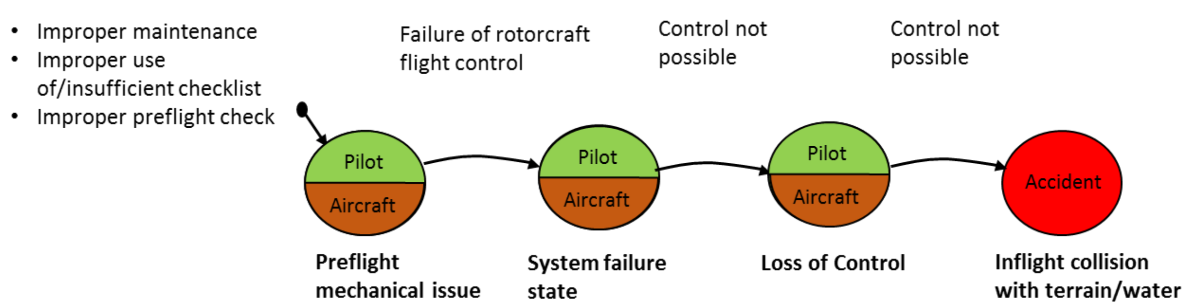


Figure 22: State-based representation of the accident sequence, which began with the system in a preflight mechanical issue state. Improper maintenance was one of the causes for this accident.

Figure 22 shows a state-based representation of the same accident. The preflight mechanical issue state was triggered by improper maintenance installation, insufficient information/checklist provided by the manufacturer, and the pilot's failure to detect the mechanical issue during a preflight check[27]. In this accident, all trigger information was available in the accident codes (see Section 4.3.2 for a discussion of cases where the trigger information is not available).

The system began operation with an existing mechanical issue. Subsequently, the cyclic control disconnected, triggering a transition to a system failure state. The failure of a critical helicopter control component (i.e., cyclic) rendered the aircraft uncontrollable (as shown by the "control not possible" trigger), triggering a transition to an inflight loss of control (LOC) state. The helicopter crashed into the surrounding terrain, fatally injuring all occupants.

**Flight that began with an impaired pilot (NTSB ID: CHI03FA181)**

In June 2003, a Robinson R44 II experienced an inflight loss of control and crashed near Coleta, IL. The accident investigation revealed that the pilot was impaired because he had taken anti-depressant drugs before the flight. During the flight, he did not maintain rotor RPM, resulting in a loss of control. He did not recover from the uncontrolled descent and crashed into the terrain.

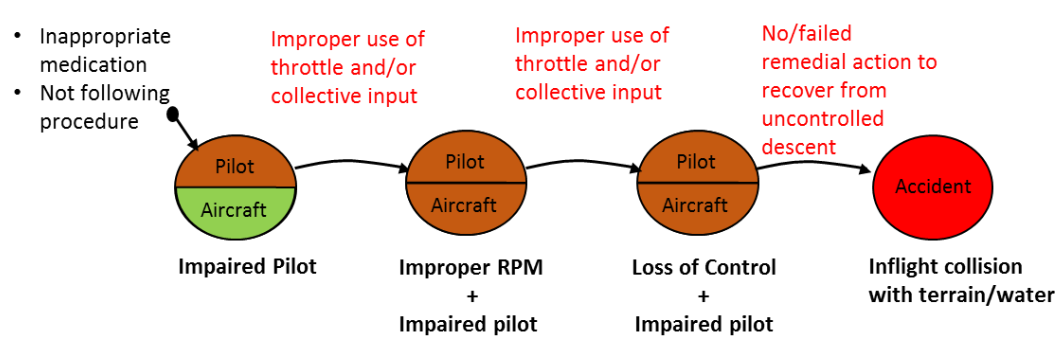


Figure 23: State-based representation of the accident sequence, which began with the system in a hazardous state owing to pilot impairment. I add the impaired pilot state to the improper RPM and loss of control states to indicate the role played by pilot

[27] Note that the preflight mechanical issue state has three triggers. I term these this succession of triggers as a "rapid sequence of triggers", which I discuss later in this Chapter.

impairment in the accident. The triggers in red were inferred as they were not recorded in the database.

Figure 23 shows a state-based representation of this accident. I inferred the trigger events labeled in red from the accident data as they were not coded in the database. In this accident, the system began in a hazardous state owing to drug consumption by the pilot, and failure to follow procedure, as shown in the first node in Figure 23. In flight, the pilot's incorrect throttle or collective input triggered a transition to the improper RPM state. Since the pilot failed to correct his throttle/collective input, the system transitioned to a loss of control state. The impaired pilot's failure to recover from the uncontrolled descent transitioned the system to a collision with terrain accident (end state).

**Flight that began in a Nominal State (NTSB ID: DEN00GA050)**

In February 2000, the pilot of a Bell OH-58A+ was executing a practice autorotation to do a functional check of the free-wheeling unit[28]. While trying to exit the autorotation, the pilot failed to follow the procedure for a power recovery (where the pilot should gently roll the throttle back on, let the engine and rotor RPM needles coincide, and raise the collective). The failed power recovery resulted in an inflight loss of control and subsequent collision with terrain. The accident killed both occupants.

[28] Helicopters are fitted with a freewheeling unit to prevent the main rotor from driving the engine in the event of the main rotor RPM exceeding the engine RPM.

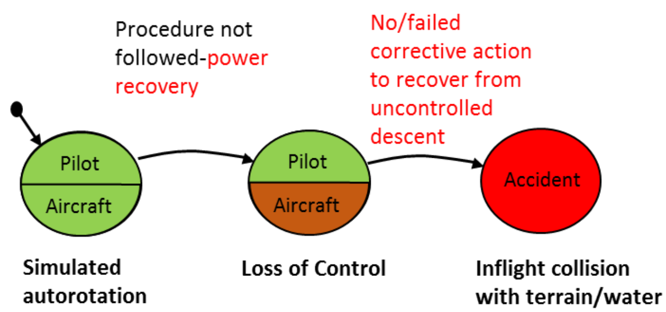


Figure 24: State-based representation of the accident sequence, which began in a nominal state during a practice autorotation, but transitioned to an inflight loss of control accident.

Figure 24 shows the state-based representation of this accident. The system began in a nominal state while practicing autorotations; however, the pilot's failure to execute a power recovery triggered a loss of control. The pilot failed to apply corrective action to recover from the loss of control state, resulting in a transition to a collision with terrain end state.

## 4.3 Using Accident Data to Create a Dictionary of Hazardous States, Triggers, and Information Codes

The state-based accident model requires a set, or vocabulary, of states and triggers that may appear in accidents. The different states and triggers can be defined using multiple potential sources (e.g., helicopter flight physics models, expert surveys). Since the focus of this thesis is to try to better understand the causes for helicopter accidents recorded in the NTSB's database, I defined states and triggers by using the codes from the NTSB's accident coding manual.

In this section, I present a set of hazardous states and triggers. These definitions are based on the NTSB accident data coding manual, as well as, where applicable, accident statistics. The NTSB coding manuals for the pre- and post-2008 systems together contain nearly 3384 different subject codes, modifiers, occurrences, and phase of flight codes. In compiling these definitions, I create a logical expression that defines how each NTSB code or set of codes is translated into states, triggers, or information codes. This set of logical expressions covers both the old (pre-2008) and current (post-2008) accident coding systems, thereby facilitating a continuity in the accident analysis. I use these logical expressions to construct a computer program (in MATLAB®) that automatically identifies the states, triggers, and information codes corresponding to accidents in the NTSB database.

### 4.3.1 Hazardous States

Using the NTSB accident codes, I defined 86 hazardous states in total. 51 hazardous states are one-to-one equivalents of occurrence or subject codes; i.e., these states correspond to only one code, and vice versa. For example, the subject code "*24802: Ground resonance*" translates directly to the ground resonance hazardous state, as shown in Table 13. The table reads as follows. The first row gives the state name. The second row explains what the state is. Next, the table shows the expression for the pre-2008 codes. In this case, the expression is a simple one-to-one correspondence. The remainder of the table gives the expression for the post-2008 system. The notes field provides information on how I identified the codes and expressions corresponding to each state.

Table 13: Ground Resonance State Definition

| **Ground Resonance** | |
|---|---|
| Hazardous state where the primary frequency of the main rotor is amplified by the stiffness (and frequency) of the landing gear, resulting in violent vibration of the helicopter. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24802: Ground resonance | I identified this state by searching the coding manual for the phrase "ground resonance".<br><br>In one case in the pre-2008 database, the NTSB did not specify a modifier while recording ground resonance. |
| **NTSB Codes (post-2008)** | **Notes** |
| 232: Ground resonance | I identified this state by searching the coding manual |

| Ground Resonance | |
|---|---|
| | for the phrase “ground resonance”. |

The NTSB coding manual has multiple codes that convey the same meaning. Further, the NTSB uses many of these codes interchangeably while recording accidents in the database. I defined 28 hazardous states by grouping subject codes, occurrences, modifiers, and phase of flight codes that conveyed the same meaning.

For example, the NTSB uses several codes to indicate inflight loss of control. Table 14 summarizes the corresponding state definition and logic expression. Each row presents a code or set of codes that translate into the state—i.e., rows are connected into a single logical expression with OR statements. For example, in this case, the pre-2008 NTSB codes 250, 110, 24566, 24539, 24524, 24525, OR 553, all translate into the “inflight loss of control” state (in some cases with appropriate modifiers, as indicated in the table). The remainder of the table gives the expression for the post-2008 system.

Table 14: Inflight Loss of Control State Definition

| **Inflight Loss of Control** | |
|---|---|
| A hazardous state that involves an unintended departure of an aircraft from controlled flight regime (FAA, 2016b). | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 250: Loss of control inflight | I identified these codes by searching the coding manual for derivatives of the word “control”.<br>I exclude codes that suggest pilot action or component failures. |
| 110: Uncontrolled altitude deviation | |
| 24566: Aircraft control AND (“not maintained” OR “not possible” OR “reduced” OR “uncontrolled”) | |
| 24539: Directional control AND (“not maintained” OR “not possible” OR “reduced” OR “uncontrolled”) | |
| 24524: Descent AND (“uncontrolled”) | |
| 24525: Descent rate AND (“uncontrolled”) | |
| 553: Uncontrolled descent | |
| **NTSB Codes (post-2008)** | **Notes** |
| 240: Inflight loss of control | |
| 01062020XX: Directional control AND (“not attained/maintained” OR “attain/maintain not possible” OR “incorrect operation/use” OR “capability exceeded”) | I identified these codes by searching the coding manual for derivatives of the word “control”. |
| 01062022XX: Pitch control AND (“not attained/maintained” OR “attain/maintain not possible” OR “incorrect operation/use” OR “capability exceeded”) | |

| Inflight Loss of Control | |
|---|---|
| 01062024XX: Yaw control AND (“not attained/maintained” OR “attain/maintain not possible” OR “incorrect operation/use” OR “capability exceeded”) | I exclude codes that suggest pilot action or component failures. |
| 02063040XX: Aircraft control | |
| 650: Uncontrolled descent | |

Using a similar process, I defined the remaining states, as shown in Tables 53 through 83 (Appendix A).

Finally, I defined 4 additional hazardous states that are not available from the NTSB codes: (1) Controlled flight into terrain (CFIT); (2) improper autorotation; (3) preflight mechanical issues; and (4) Preflight pilot hazardous state.

Controlled flight into terrain/object (CFIT) is a hazardous state where an airworthy aircraft, which is under pilot control, is inadvertently flown into terrain, water or an object. The NTSB's post-2008 coding system has a code that matches this state, i.e., “*120: Controlled flight into terrain/object*”. The pre-2008 system does not have a similar code. Thus, I defined the CFIT state for the pre-2008 system as shown in Table 15.

Table 15: Controlled Flight into Terrain/Object (CFIT) State Definition

| Controlled Flight into Terrain/Object (CFIT) | |
|---|---|
| Hazardous state where which an airworthy aircraft (under pilot control) is inadvertently flow into terrain, water, or an object. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 230: Inflight collision with terrain/water AND NOT (Inflight loss of control state OR loss of engine power state OR system failure state) | The definition for CFIT indicates that the aircraft should be airworthy and under the control of the pilot at the time of impact. Thus, I defined this state as any collision with terrain/object that did not involve any issues with the engine or systems (which satisfies the definition of airworthy), and did not involve loss of control |
| 220: Inflight collision with object AND NOT (Inflight loss of control state OR loss of engine power state OR system failure state) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 120: Controlled flight into terrain/object | The post-2008 coding system has a code that is a one-to-one map for the CFIT state. |

Autorotation is a state of helicopter flight where the main rotor blades are driven only by aerodynamic forces and not by the engine. Helicopter pilots are trained to perform autorotative landings in the event of losing engine power. To execute a successful autorotation, pilots are instructed to maintain best gliding airspeed and requisite rotor RPM (through collective inputs), perform a flare (by aft cyclic motion) to reduce airspeed and maintain the correct descent angle and rate, and finally perform a safe landing.

While there might be situations where correctly-performed autorotations ended in accidents due to unfavorable terrain; here, I want to identify those autorotations that were not correctly executed, i.e., improper autorotations. Table 16 presents the different logical expressions that define an improper autorotation.

Table 16: Improper Autorotation State Definition

<table>
<tr><th colspan="2">Improper Autorotation</th></tr>
<tr><td colspan="2">Hazardous state where the pilot failed to maintain key flight parameters like rotor RPM, descent, airspeed, altitude, or flare during autorotation.</td></tr>
<tr><th>NTSB Codes (pre-2008)</th><th>Notes</th></tr>
<tr><td>24520: Autorotation AND (24518: Altitude AND (“inadequate” OR “misjudged” OR “low” OR “improper” OR “not maintained” OR “delayed” OR “below” OR “unavailable” ))</td><td rowspan="6">The key elements to a successful autorotation are:<br>• Maintaining rotor RPM<br>• Maintaining airspeed<br>• Performing a correct descent, with proper descent rate<br>• Performing a correct flare (or level-off)<br><br>I combined the 24520: Autorotation code with the codes corresponding to each of the above elements (along with the logical expressions for each of the elements).<br><br>I included the 24520 code with the modifiers that suggested improper autorotation.</td></tr>
<tr><td>24520: Autorotation AND (24519: Proper altitude AND (“not maintained” OR “not attained” OR “exceeded” OR “below” OR “misjudged”))</td></tr>
<tr><td>24520: Autorotation AND (24524: Descent AND (“excessive” OR “not maintained” OR “exceeded”, “improper” OR “inadvertent” OR “intentional” OR “uncontrolled”, “misjudged” OR “premature” OR “not maintained/obtained” OR “not possible” OR “not corrected” OR “intentional” OR “premature”)</td></tr>
<tr><td>24520: Autorotation AND (24525: Proper descent rate AND (“excessive” OR “not maintained” OR “exceeded” OR “improper” OR “inadvertent” OR “intentional” OR “misjudged” OR “uncontrolled” OR “not maintained/obtained” OR “not possible” OR “not corrected”))</td></tr>
<tr><td>24520: Autorotation AND (24535: Flare AND (“misjudged” OR “not possible” OR “not attained”, “delayed” OR “inadequate” OR “low” OR “high” OR “premature” OR “reduced” OR “abrupt” OR “improper” OR “not possible” OR “excessive” OR “not performed” OR “abrupt” OR “inaccurate” OR “not successful” ))</td></tr>
<tr><td>24520: Autorotation AND (24534: Level-off AND (“improper” OR “not possible” OR “misjudged” OR “not attained” OR “delayed” OR “inadequate” OR “premature” OR “high”))</td></tr>
</table>

| **Improper Autorotation** | |
|---|---|
| Hazardous state where the pilot failed to maintain key flight parameters like rotor RPM, descent, airspeed, altitude, or flare during autorotation. | |
| 24520: Autorotation AND (24803: Height/velocity curve AND (“exceeded” OR “not complied with” OR “below” OR “not followed” OR “not attained” OR “disregarded” OR “low” OR “intentional” OR “not obtained/maintained”)) | I included the forced landing occurrence and the emergency descent phase of flight code |
| 24520: Autorotation AND (22308: Adequate rotor RPM AND (“not maintained” OR “not possible” OR “not attained” OR “not available” OR “misjudged” OR “not followed” OR “delayed”)) | |
| 24520: Autorotation AND (24558: Rotor RPM AND (“not maintained” OR “misjudged” OR “low” OR “high” OR “inadequate” OR “reduced” OR “excessive” OR “exceed” OR “improper” OR “diminished” OR “ not possible” OR “diminished” OR “not verified” OR “not identified” OR “not corrected” OR “not obtained/maintained” OR “not attained”) | |
| 24520: Autorotation AND (24506: Airspeed AND (“not maintained” OR “excessive” OR “inadequate” OR “low” OR “misjudged” OR “not attained” OR “reduced” OR “not obtained/maintained” OR “misjudged” OR “below” OR “exceeded” OR “initiated” OR “high” OR “excessive”)) | |
| 24520: Autorotation AND (24509: Airspeed-minimum control speed with the critical engine inoperative AND (“not maintained”)) | |
| 24520: Autorotation AND (24516: Airspeed-maximum operating limit speed AND (“exceeded”)) | |
| 24520: Autorotation AND (“misjudged” OR “poor” OR “improper” OR “delayed” OR “not maintained” OR “improper use of” OR “inadequate” OR “uncontrolled” OR “restricted” OR “not obtained” OR “not successful” OR “not identified” OR “premature”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 601: Autorotation AND (01062037XX: Descent rate OR 01062040XX: Descent/approach/glide path OR 01062041XX: Landing flare OR 01062010XX: Airspeed OR 01062012XX: Performance/control parameters-altitude OR 01062052XX: Performance/control parameters-Prop/rotor parameters | In the post-2008 system, the NTSB records autorotation as a phase of flight with the code 601. This code does not have any modifiers associated with it. Similar to the pre-2008 system, I build logical expressions that include the autorotation code and subject codes corresponding to the key elements of an autorotation. |
| 601: Autorotation AND (01062037XX: Descent rate AND (“not attained/maintained” OR “incorrect use/operation” OR “capability exceeded” OR “attain/maintain not possible” OR “not specified” OR “related operating info”)) | |
| 601: Autorotation AND (01062040XX: Descent/approach/glide AND (“not attained/maintained” OR “incorrect use/operation” OR “capability exceeded” OR “attain/maintain not possible” OR “not specified”)) | |
| 601: Autorotation AND (01062041XX: Landing flare AND (“not attained/maintained” OR “incorrect use/operation” OR “not specified”)) | |
| 601: Autorotation AND (01062010XX: Airspeed AND (“not attained/maintained” OR “capability exceeded”)) | |
| 601: Autorotation AND (01062012XX: Performance/control parameters-altitude altitude AND (“not attained/maintained” OR “attain/maintain not possible” OR “incorrect use/operation OR “related operating info”)) | |
| 601: Autorotation AND (01062052XX: Performance/control parameters-Prop/rotor parameters AND (“not attained/maintained” OR “attain/maintain not possible” OR “capability exceeded”)) | |

The definitions for preflight mechanical issues and preflight pilot hazardous state are shown in Tables 70 and 71, respectively (see Appendix A).

### 4.3.2 Triggers

Using the NTSB accident codes, I defined 182 triggers. Similar to one-to-one states, 95 triggers are direct equivalents of a subject or occurrence code. For example, the subject code "*24705: Control interference*" translates to the trigger event "*Control interference*" (Table 17). The 95 triggers that are direct equivalents are shown in Tables 210 through 308 (Appendix B).

Table 17: Control interference Trigger Definition

| **Control interference** | |
|---|---|
| This trigger, as the name suggests, impedes the pilot from controlling the aircraft. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24705: Control interference AND ("inadvertent" OR "encountered" OR "improper" OR "conflicting" OR "not removed" OR "excessive" OR "performed" OR "initiated") | Note that the NTSB used the "performed" modifier to indicate control interference by a passenger, and "initiated" when a pilot tried to take over the controls when another pilot was flying the helicopter |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Similar to the process I followed for defining "many-to-one" hazardous states, I defined 26 many-to-one triggers by combining NTSB codes that conveyed the same meaning. Table 18 defines the *failure to remove aircraft/rotor tie-down* trigger. Tables 135 through 159 (Appendix B) present these triggers.

Table 18: Failure to Remove Aircraft/Rotor Tie-down Trigger Definition

| **Failure to Remove Aircraft/Rotor Tie-down** | |
|---|---|
| This trigger represents failure of ground personnel or pilot(s) to remove a tie-down before flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23316: Ground tie-down rope/strap AND ("not removed") | I identified these codes by searching the coding manual for the phrase "tie-down". I did not include the code that |
| 17118: Miscellaneous equipment/furnishings—Aircraft tie-down(s) AND ("not removed" OR "separation" OR "entangled") | |
| 24008: Tie down AND ("not removed") | |

| Failure to Remove Aircraft/Rotor Tie-down | |
|---|---|
| 24810: Rotor blade tie-down(s) AND ("not removed") | corresponded to securing cargo under this trigger. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01011020XX: Aircraft handling/service—Parking/securing-Tie-down/mooring | I identified these codes by searching the coding manual for the phrase "tie-down". I did not include the code that corresponded to securing cargo under this trigger. |
| 01011000XX: Aircraft handling/service—Parking/securing (general) AND ("incorrect use/operation") | |

Table 19 shows the definition for the improper preflight planning trigger. I searched the coding manual for the word "preflight", and derivatives of the word "plan" and "prepare". Table 19 shows the codes and logical statements for this trigger. The codes in the pre-2008 system (24001, 24002, and 24405) convey the same meaning—that the pilot did not carry out a proper preflight plan.

Table 19: Improper Preflight Planning Trigger Definition

| Improper Preflight Planning | |
|---|---|
| This trigger represents incorrect or insufficient planning by the pilot(s) before flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24001: Preflight planning/preparation AND ("inadequate" OR "improper" OR "poor" OR "not performed" OR "inaccurate" OR "intentional") | First, I searched for the word "preflight" and derivatives of the word "plan" and "prepare" in the NTSB coding manual. I did not include codes for inflight planning. |
| 24002: Aircraft preflight AND ("improper" OR "inadequate" OR "poor" OR "not performed" OR "inaccurate" OR "disregarded") | |
| 24405: Preflight briefing service OR ("not obtained" OR "not used" OR "improper use of" OR "incorrect") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 030: Preflight/dispatch event | First, I searched for the word "preflight" and derivatives of the word "plan" and "prepare" in the NTSB coding manual.<br><br>While these codes do not necessarily convey the same meaning, they can be placed under a hierarchy for preflight planning (see Figure 8). |
| 02061000XX: Planning/preparation (general) | |
| 02061010XX: Planning/preparation—Performance calculations | |
| 02061015XX: Planning/preparation—Weight/balance calculations | |
| 02061020XX: Planning/preparation—Weather planning | |
| 02061025XX: Planning/preparation—Flight planning/navigation | |
| 02061030XX: Planning/preparation—Fuel planning | |

All the post-2008 codes classified under the improper preflight planning trigger system do not necessarily convey the same meaning; however, they can be placed in an improper preflight planning hierarchy (Figure 25). Using this hierarchy facilitates counting not just the number of instances improper preflight planning triggered hazardous states, but also the number of times each of the constituents of the hierarchy appeared in accidents.

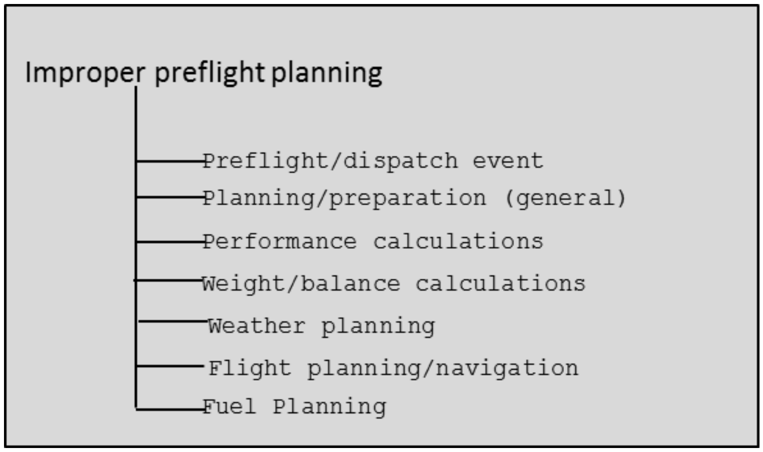


Figure 25: A trigger hierarchy for improper preflight planning. Using this hierarchy facilitates counting not just the number of instances improper preflight planning (top-level trigger) triggered hazardous states, but also the number of times each of the constituents (second-level triggers) of the hierarchy appeared in accidents.

Similar to preflight planning, consider the example of the “rotorcraft flight control failure” trigger, shown in Table 20. Here, each of the rows are individual triggers that can also be grouped under the “rotorcraft flight control failure” hierarchy, as suggested by the hierarchies in the NTSB coding manual. I tabulate similar such hierarchies in Tables 160 through 209 (Appendix B), and use the blue shade for convenient identification.

Table 20: Using the existing NTSB hierarchy of subject codes to define the rotorcraft flight control failure trigger. These codes indicate structural failure/malfunction of rotorcraft flight control components

| **Rotorcraft Flight Control Failure** | |
|---|---|
| This trigger represents failure of a flight control component. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 10900: Rotorcraft flight control (general) AND (“disconnected” OR “separation” OR “cut/severed” OR “jammed” OR “fatigue” OR “inadequate” OR “undetermined” OR “disabled” OR “vibration” OR “failure-total” OR “failure”) | These codes are those given the NTSB hierarchy. Each row is an individual (second-level) trigger. |
| 10901: Rotorcraft flight control-cyclic control AND (“disconnected” OR “separation” OR “cut/severed” OR “jammed” OR “fatigue” OR “inadequate” OR “undetermined” OR “inoperative” OR “lock” OR “not | |

| **Rotorcraft Flight Control Failure** | |
|---|---|
| This trigger represents failure of a flight control component. | |
| safetied" OR "seized" OR "fractured" OR "oscillation") | |
| 10902: Rotorcraft flight control-cyclic control rod AND ("fractured" OR "separated" OR "corroded" OR "disconnected" OR "movement restricted" OR "overload" OR "failure-partial" OR "failure-total" OR "not safetied" OR "not installed" OR "fatigue") | |
| 10903: Rotorcraft flight control-cyclic bellcrank AND ("failure-total" OR "disconnected" OR "inadequate" OR "fatigue") | |
| 10904: Rotorcraft flight control-collective control AND ("unlocked" OR "worn" OR "inoperative" OR "failure-total" OR incorrect" OR "undetermined" OR "locked" OR "failure" OR "failure-partial" OR "blocked-partial" OR "disabled" OR "movement restricted" OR "not secured") | |
| 10905: Rotorcraft flight control-collective control rod AND ("fatigue" OR "failure-total" OR "disengaged" OR "overload" OR "disconnected") | |
| 10906: Rotorcraft flight control-collective bellcrank AND ("jammed" OR "improper") | |
| 10908: Rotorcraft flight control-tail rotor pedal AND ("vibration" OR "jammed" OR "blocked-total" OR "cut/severed") | |
| 10909: Rotorcraft flight control-tail rotor control AND ("loss-total" OR "undetermined" OR "failure" OR "disconnected" OR "fatigue" OR "incorrect" OR "failure-total" OR "loss-partial" OR "movement restricted" OR "worn" OR "disabled" OR "lack of" OR "inoperative") | |
| 10910: Rotorcraft flight control-tail rotor bellcrank AND ("fatigue") | |
| 10911: Rotorcraft flight control-tail rotor cable AND ("failure-total" OR "chafed" OR "fractured" OR "failure" OR "loose part" OR "separation" OR "undetermined" OR "corroded" OR "movement restricted" OR "disengaged" OR "worn" OR "overload") | |
| 10912: Rotorcraft flight control-mixing unit AND ("fatigue" OR "disconnected" OR "failure-total" OR "separation") | |
| 10914: Rotorcraft flight control-rotating scissors AND ("disconnected") | |
| 10915: Rotorcraft flight control-swashplate assembly AND ("disconnected" OR "disengaged" OR "over-temperature" OR "seized" OR "failure-total" OR "failure-partial" OR "jammed" OR "fatigue") | |
| 10916: Rotorcraft flight control-pitch change rod/link AND ("overload" OR "loose part" OR "failure-total" OR "fracture" OR "fatigue") | |
| 10917: Rotorcraft flight control-pitch change horn AND ("separation" OR "loose part" OR "failure-total") | |

| Rotorcraft Flight Control Failure | |
|---|---|
| This trigger represents failure of a flight control component. | |
| 10918: Rotorcraft flight control-synchronized elevator control AND (“separation”) | |
| 10920: Rotorcraft flight control-control rod bearing AND (“worn” OR “failure-total” OR “separation”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01046700XX: Rotorcraft flight control (general) AND (“failure” OR “malfunction”) | I identified these codes by searching for the “rotorcraft flight control” hierarchy in the NTSB coding manual.<br>Each row is an individual (second-level) trigger. |
| 01046710XX: Rotorcraft flight control—Main rotor control AND (“failure” OR “damaged/degraded”) | |
| 01046720XX: Rotorcraft flight control—Tail rotor control AND (“failure”) | |
| 01046730XX: Rotorcraft flight control—Rotorcraft servo system AND (“failure” OR “fatigue/wear/corrosion”) | |

#### 4.3.2.1 Trigger Definitions Based on Position in Accident Sequence

I defined four triggers as a combination of codes and their position in the state transition sequence. I discuss the approach to identifying these triggers in more detail in Section 4.4.2 (after presenting the rules for sequencing states). Tables 21 through 24 present the definitions of these triggers.

Table 21: Clipping of Object/Terrain Trigger Definition

| Clipping of Object/Terrain | |
|---|---|
| This trigger represents clipping of an object or terrain during flight. I defined this trigger after sequencing states. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 220: Inflight collision with object AND NOT (an end state) AND NOT (“170: Fire/explosion” OR “171: Fire” as end state) | I identified these codes by searching the coding manual for the phrases “collision with object” and “collision with terrain”. I used the state sequence to ensure that these codes were not end states.<br><br>In some cases, a post-impact fire can result from a collision. In such scenarios, I treat the collision as the end state (and the fire/explosion results from the end state). |
| 230: Inflight collision with terrain/water AND NOT (an end state) AND NOT (“170: Fire/explosion” OR “171: Fire” as end state) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 470: Collision with terrain/object AND NOT (an end state) AND NOT (“170: Fire/smoke post-impact” OR “180: Explosion post-impact” as end state) | I identified these codes by searching the coding manual for the phrases “collision with |

| Clipping of Object/Terrain | |
|---|---|
| 120: Controlled flight into terrain AND NOT (an end state) AND NOT ("170: Fire/smoke post-impact" OR "180: Explosion post-impact" as end state) | object" and "collision with terrain". I used the state sequence to ensure that these codes were not end states. I also include cases where the NTSB reports CFIT; however, CFIT was not the end state.<br><br>In some cases, a post-impact fire can result from a collision. In such scenarios, I treat the collision as the end state (and the fire/explosion results from the end state). |

Table 22: Clipping of Wing/Rotor Trigger Definition

| Clipping of Wing/Rotor | |
|---|---|
| This trigger represents clipping of wing/rotor during flight. I defined this trigger after sequencing states. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 160: Dragged wing/rotor/float/other AND NOT (an end state) AND NOT ("170: Fire/explosion" OR "171: Fire" as end state) | I identified these codes by searching the coding manual for the phrases "dragged wing". I used the state sequence to ensure that these codes were not end states.<br><br>In some cases, a post-impact fire can result from a collision. In such scenarios, I treat the collision as the end state (and the fire/explosion results from the end state). |
| **NTSB Codes (post-2008)** | **Notes** |
| 093: Dragged wing/rotor/float/other AND NOT (an end state) AND NOT ("170: Fire/smoke post-impact" OR "180: Explosion post-impact" as end state) | I identified these codes by searching the coding manual for the phrases "dragged wing". I used the state sequence to ensure that these codes were not end states.<br><br>In some cases, a post-impact fire can result from a collision. In such scenarios, I treat the collision as the end state (and the fire/explosion results from the end state). |

Table 23: Clipping in Midair Trigger Definition

| **Clipping in Midair** | |
|---|---|
| This trigger represents clipping of another aircraft during flight. I defined this trigger after sequencing states. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 270: Midair collision AND NOT (an end state) | I identified this code by searching the coding manual for the word “midair”. I used the state sequence to ensure that the midair collision was not the end state. |
| **NTSB Codes (post-2008)** | **Notes** |
| 250: Midair collision AND NOT (an end state) | I identified this code by searching the coding manual for the word “midair”. I used the state sequence to ensure that the midair collision was not the end state. |

Table 24: Inflight fire/explosion Trigger Definition

| **Inflight Fire/Explosion** | |
|---|---|
| This trigger represents fire/explosion that occurred during flight (before impact). I defined this trigger after sequencing states. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 170: Fire/explosion AND NOT (an end state) | I identified these codes by searching the coding manual for the words “fire” and “explosion”. I also used the state sequence to ensure these codes were not end states |
| 171: Fire AND NOT (an end state) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 150: Fire/smoke (non-impact) | I identified these codes by searching the coding manual for the words “fire” and “explosion”. In the post-2008 system, the NTSB clearly distinguishes between post-impact and non-impact fires/explosion |

Finally, I defined the “time spent in poor weather” trigger as the time spent in poor weather trigger that causes the system to move from a poor weather hazardous state to the disoriented/lack of awareness state (Table 25). A (non-instrument rated) pilot relies on visual cues to correctly orient the aircraft relative to the environment (ATSB, 2011). The obscuration of these visual cues during flight in poor weather (IMC conditions) and light conditions can result spatial disorientation. The *NTSB coding manual does not contain* a trigger for the disoriented/lacking awareness state.

Table 25: Time Spent in Poor Weather Trigger Definition

| **Time Spent in Poor Weather** | |
|---|---|
| This trigger causes the system to move from a poor weather state to a disoriented/lack of awareness state. | |
| **User-defined Code** | **Notes** |
| I defined the time spent in poor weather trigger that causes the system to move from a poor weather hazardous state to the disoriented/lack of awareness state. | This trigger is inferred when the NTSB accident report does not indicate how the system transitioned from the poor weather state to the disoriented/lack of awareness state. |

### 4.3.3 Information Codes

In some cases, the NTSB codes are neither triggers nor hazardous states—they provide additional information about hazardous states. I term these codes as *information* codes. For example, "*19200: Terrain*" and "*20200: Object*" codes provide additional information about the terrain or object, but do not describe a hazardous state of the system, nor a trigger that could cause a transition. An aircraft's phase of flight can also be considered as an information code (with the exception of "*553: uncontrolled descent*", which describes inflight loss of control and "*601: Autorotation*", which indicates that the pilot performed an autorotation).

#### 4.3.3.1 Information about Object

In the pre-2008 system, the NTSB used "*20200: Object*" frequently in accidents that involved "*220: Collision with object*" hazardous state (or clipping trigger event). The modifiers associated with the subject code provide additional information about the type of object the aircraft encountered (e.g., transmission wire, pole, or trees).

Table 26: Information about the Objects that Aircraft Collided with During Accidents (post-2008)

| **Information about Object** | |
|---|---|
| This code contains detailed information about the specific objects that aircraft collided with during flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| Tree(s) | These codes are modifiers associated with the subject code 20200: Object in the pre-2008 coding system.<br><br>The NTSB used the object code (along with modifiers) to provide additional information regarding the object that the aircraft clipped/collided with during flight. |
| Wire, transmission | |
| Wire, static | |
| Vehicle | |
| Fence | |
| Other | |
| Building (non-residential) | |
| Utility pole | |
| Pole | |
| Residence | |
| Bird(s) | |
| Aircraft parked/standing | |
| Other person | |
| Airport facility | |
| Guy wire | |
| Hangar/airport building | |
| Tower | |
| Animal(s) | |
| Fence post | |
| Aircraft moving on ground | |
| Not specified in NTSB manual | |
| Undetermined | |
| Wall/barricade | |
| Electrical tower | |
| Wire, transmission (marked) | |
| Sign | |
| Antenna | |
| Wind sock/indicator | |
| Airport sign/marker | |
| Tower (marked) | |
| Runway light | |
| Electrical tower (marked) | |
| Wire, static (marked) | |
| Other | |
| Ditch | |
| High obstruction(s) | |
| Downhill | |
| Approach light/navigation aid | |
| **NTSB Codes (post-2008)** | **Notes** |
| Pole | These codes are modifiers associated with the subject code 030220XXXX: Object/animal/substance in the post-2008 coding system.<br><br>The NTSB uses the object code (along with modifiers) to |
| Runway/taxi/approach light | |
| Sign/marker | |
| Tower/antenna (including guy wires) | |
| Tree(s) | |
| Residence/building | |
| Ground vehicle | |
| Wall/barricade | |

| Information about Object | |
|---|---|
| This code contains detailed information about the specific objects that aircraft collided with during flight. | |
| Wind sock | provide additional information regarding the object that the aircraft clipped/collided with during flight. |
| Wire | |
| Person | |
| Bridge/overpass | |
| Aircraft | |
| Airport structure | |
| Animal(s)/bird(s) | |
| Fence/fence post | |
| Ground equipment | |
| Hidden/submerged object | |
| Debris/dirt/foreign object | |
| Water/moisture | |
| Snow/ice | |

For accidents recorded in the post-2008 system, the NTSB provided information about the nature of the object under the "*03022000XX–03022055XX: Object/animal/substance*" hierarchy. The codes in this hierarchy were associated with modifiers such as "*contributed to outcome*" and "*effect on equipment*", which provide some insight into the role of the object in the accident.

Tables 410 through 412 (Appendix E) provides the description for different types of terrain, airport conditions/facilities, and flight phases.

## 4.4 Creating the Grammar for the State-based Accident Model

In the previous section, I presented the vocabulary to define states and triggers, and compiled the dictionary (of states and triggers) for the state-based accident model. Now, I proceed to create the "grammar" that contains the rules for: (1) sequencing the different states in accidents; and, (2) linking triggers to states.

### 4.4.1 Sequencing (Ordering) of Hazardous States

In this section, I present the rules for arranging the different hazardous states in accidents. Figure 26 shows a simple representation of the working of the computer program that sequences the states.

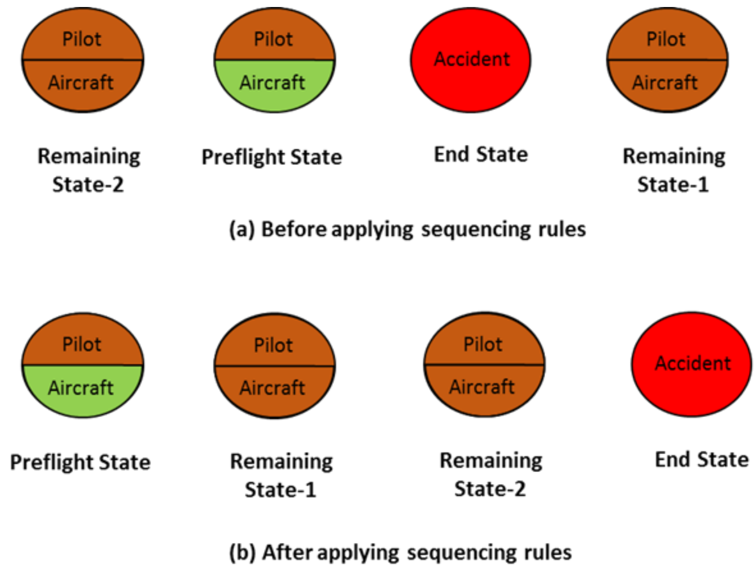


Figure 26: Demonstrating the working of the algorithm on a notional accident sequence. The top half of the figure (a) shows the unordered set of states in the accident, and (b) shows the states arranged in order after applying the sequencing rules.

The top half of Figure 26 shows the unordered states from the accident report. The algorithm begins by identifying the preflight hazardous states and end/terminating state, and placing them at the beginning and end of the accident sequence, respectively. Then, the algorithm applies the sequencing rules (that I present in this chapter) to order the remaining states, providing the final ordered set of hazardous states in the accident.

Before presenting the rules for sequencing (ordering) the different hazardous states, I sort the hazardous states (from the dictionary) into: (1) preflight hazardous states; (2) end or terminating states; and, (3) remaining states.

**Preflight Hazardous State:** as the name suggests, is a hazardous state that appears before flight; i.e., hazardous system states before being airborne. As stated earlier, the system can be in a hazardous state if either of the system's constituents (i.e., pilot or aircraft) is in a hazardous state. Preflight pilot hazardous states include physically impaired pilot, poor psychological/mental state, and the pilot's lack of experience or qualification. Preflight hazardous state for the aircraft is due to mechanical issues that generally result from improper maintenance and poor design. Table 27 shows all of the possible preflight hazardous states. If more than one of these codes appeared, then the algorithm puts them in the order specified in the table.

Table 27: Possible Preflight Hazardous States in Accidents

| **Preflight Hazardous States** | |
|---|---|
| Hazardous states that appear in the beginning of an accident sequence. | |
| **Can appear at the beginning of an accident sequence** | **Notes** |
| Preflight mechanical issue | If more than one of these codes appeared, then the algorithm puts them in the order specified in the table.<br><br>I classified improper supervision as a preflight hazardous state as it represents the instructor's hazardous attitude.<br><br>The low fuel, oil, and grease states are preflight states only if they are triggered by improper preflight planning by the pilot, improper maintenance by ground personnel (not filling/applying the correct amount of fluid).<br><br>The NTSB used the codes corresponding to anxiety or pressure to indicate hazardous pilot mental state prior to flight**.** |
| Physically impaired/incapacitated state | |
| Poor Psychological state | |
| Improper supervision state | |
| Insufficient qualification/training state | |
| Overconfidence/Lack of confidence | |
| Fatigued/overworked state | |
| Anxiety/under pressure state | |
| Preflight pilot issue (non-impairment/psychological/confidence/fatigue) | |
| Unattended aircraft state | |
| Low fuel state | |
| Low oil state | |
| Low grease state | |
| Prevailing/existing weather and light | |

**End State:** or terminating state, is a state that appears at the end of an incident or accident sequence. Hard landing, rollover, and collision with terrain/water are some examples for end states. Table 28 provides the 13 possible end states for accident sequences.

Table 28: Possible End/Terminating States in Accidents

| **End/Terminating States** | |
|---|---|
| Hazardous states that appear in the end of an accident sequence. | |
| **Can appear at the end of an accident sequence** | **Notes** |
| Midair collision | I identified 13 end possible end states.<br><br>The NTSB combined the collision with object and terrain codes in the post-2008 system<br><br>In the pre-2008 system, the NTSB sometimes used the 180: Forced landing occurrence to indicate: (1) an end state; and in some cases (2) an emergency descent. |
| Forced/emergency landing | |
| Collision during takeoff/landing | |
| Inflight collision with terrain/water/object | |
| Hard landing | |
| Dragged wing/rotor/float | |
| On-ground collision with terrain/object | |
| Rollover | |
| Nose down/nose over | |
| Controlled flight into terrain/object | |
| Ditching | |
| Abnormal runway contact | |
| Fire/explosion | |

**Intermediary States:** are those hazardous states that are neither preflight nor end states. Examples for remaining states include inflight loss of control, loss of engine power, and low rotor RPM states.

Now, I present the rules for sequencing the intermediary hazardous states. Consider the vortex ring state (also referred to as VRS or the settling with power state), which occurs when a rapidly descending helicopter’s main rotor blades are engulfed by a doughnut-shaped vortex. The circulation of air at the rotating blade tips is pushed downwards by aerodynamic forces resulting in a vortex, which reduces the lift and increases the drag on the blades. A rapidly descending helicopter experiences increased upward flow of air at the blade root and eventual blade root stall.

Table 29 shows the hazardous states that can appear immediately after a vortex ring state. Each row contains a hazardous state that can potentially appear immediately after VRS. If more than one of the states is recorded in an accident that involved VRS, the states are arranged in the same order specified in Table 29.

Table 29: Sequencing Rules for Vortex Ring State

| **Vortex Ring State** | |
|---|---|
| Hazardous state where a rapidly descending helicopter's main rotor blades are engulfed by a doughnut-shaped vortex, resulting in a loss of lift. | |
| **States that can appear immediately after are** | **Notes** |
| Improper altitude/clearance | A high rate of descent, low airspeed, and applying more than 20% of available engine power to the rotor RPM can lead to vortex ring state.<br>After entering the vortex ring state, generally, the helicopter experiences a loss of altitude.<br>In some cases, the tail rotor enters a vortex ring state, resulting in a loss of tail rotor effectiveness (LTE).<br>Failure to recover from LTE can result in an inflight loss of control. |
| Loss of Tail Rotor Effectiveness (LTE) | |
| Loss of control | |
| Improper go-around | |

Maintaining airspeed is critical to helicopter safety during forward flight. Failing to maintain airspeed can result in hazardous states such as improper translational lift, loss of tail rotor effectiveness, and aircraft/blade stall. Table 30 presents the different hazardous states that can appear immediately after the improper airspeed hazardous state.

Table 30: Sequencing Rules for Improper Airspeed State

| **Improper Airspeed State** | |
|---|---|
| Hazardous state where the pilot fails to maintain the correct airspeed during flight. | |
| **States that can appear immediately after are** | **Notes** |
| Improper descent | Maintaining airspeed is critical to helicopter safety during forward flight.<br><br>Pilot can control the airspeed using the throttle (when the |
| Improper altitude/clearance | |
| Improper RPM | |
| Improper translational lift | |
| Vortex ring state | |
| Loss of tail rotor effectiveness (LTE) | |

| Improper Airspeed State | |
|---|---|
| Hazardous state where the pilot fails to maintain the correct airspeed during flight. | |
| Inflight loss of control | engine is operational) or by manipulating cyclic and collective controls. |
| Improper flare | |

Ground resonance is a hazardous state where the primary frequency of the main rotor is amplified by the stiffness (and frequency) of the landing gear, resulting in violent vibration of the helicopter. This phenomenon occurs when an improper landing causes helicopter airframe to jolt or bounce. Table 31 shows the different hazardous states that can appear immediately after the ground resonance state.

Table 31: Sequencing Rules for Ground Resonance State

| **Ground Resonance State** | |
|---|---|
| Hazardous state where the primary frequency of the main rotor is amplified by the stiffness (and frequency) of the landing gear, resulting in violent vibration of the helicopter. | |
| **States that can appear immediately after are** | **Notes** |
| Inflight loss of control | Ground resonance occurs when the helicopter touches down incorrectly.<br><br>This phenomenon occurs in fully articulated rotor systems where each blade is attached to the rotor hub through a hinge, and can move independently of the other blades.<br><br>Owing to the violent vibration during ground resonance, parts of the helicopter can break-off, transitioning to a system failure state. |
| On-ground loss of control | |
| System failure | |

In certain cases, the positions of some states in the sequence are interchangeable. Improper rotor RPM and improper airspeed are examples of hazardous states whose positions can be interchanged in the accident sequence. Consider for example an accident involving a Hiller UH-12B that occurred in 1986, near Fall River, KS (NTSB ID: MKC86FA082). The accident report mentioned that the pilot failed to maintain airspeed and RPM during the descent. Here, the system (aircraft and pilot) first entered an improper airspeed state followed by an improper RPM state. Consider another accident where the order of the improper RPM and airspeed hazardous states is flipped. The fatal accident occurred near Niles, OH, when a kit-built Rotorway Scorpion collided with terrain, killing the pilot (NTSB ID: CHI82FA260). Here, the pilot failed to correct a low RPM state before transitioning to an improper airspeed hazardous state. I handle such interchangeable situations by placing them in the order in which they are mentioned in the accident reports. Table 32 shows the different hazardous states that can appear immediately after an improper RPM state.

Table 32: Sequencing Rules for Improper RPM State

<table>
<tr><th colspan="2">Improper RPM State</th></tr>
<tr><td colspan="2">Hazardous state where the pilot fails to maintain the correct rotor RPM during flight.</td></tr>
<tr><th>States that can appear immediately after are</th><th>Notes</th></tr>
<tr><td>Improper climb</td><td rowspan="9">Set of hazardous states that can appear immediately after the improper RPM state.<br><br>The helicopter flying handbook emphasizes the importance of maintain rotor RPM by comparing it to “life” (FAA, 2016c). The appearance of several key hazardous states after the improper RPM state justifies equating this state to life.</td></tr>
<tr><td>Improper altitude/clearance</td></tr>
<tr><td>Improper airspeed</td></tr>
<tr><td>Improper translational lift</td></tr>
<tr><td>Improper descent</td></tr>
<tr><td>Vortex ring state</td></tr>
<tr><td>Loss of tail rotor effectiveness (LTE)</td></tr>
<tr><td>Inflight loss of control</td></tr>
<tr><td>Improper flare</td></tr>
</table>

Similarly, I present the rules for the remaining hazardous states in Tables 309 through 358 (see Appendix C).

### 4.4.2 Linking States and Triggers

After sequencing the hazardous states, I specify the rules that link the different triggers and hazardous states. Figure 27 shows a simple representation of the working of the computer program that links the triggers into (and out of) each hazardous state.

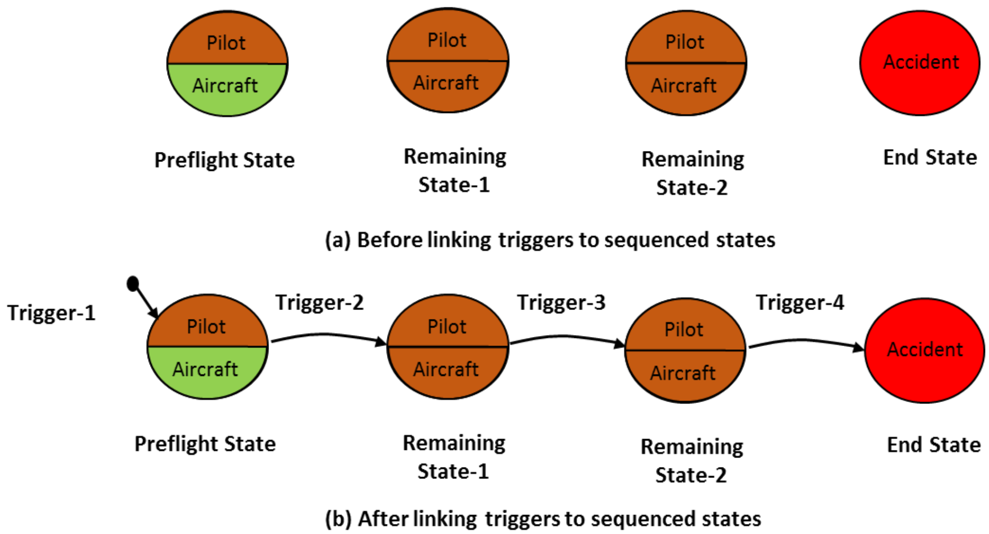


Figure 27: Demonstrating the working of the algorithm on a notional accident sequence. The top half of the figure (a) shows sequenced and unlinked hazardous states, and (b) shows the triggers linked to each hazardous state.

The computer program takes in the sequenced set of hazardous states for each accident and uses the rules I specified to link hazardous states and triggers.

There is a clear relationship between some triggers and hazardous states (e.g., loss of engine power, system failure state). Table 33 shows the different triggers for the loss of engine power state. If more than one of these triggers appears in an accident report, I group the triggers and refer to the group as a “rapid sequence of triggers”.

Table 33: Triggers into the Loss of Engine Power State

| **Loss of Engine Power State** | |
|---|---|
| Hazardous state where the aircraft has lost engine power. | |
| **Triggers into this state are** | **Notes** |
| Engine assembly failure | There is a clear relationship between these triggers (e.g., combustion assembly failure) |
| Compressor assembly failure | |
| Combustion assembly failure | |

| Loss of Engine Power State | |
|---|---|
| Hazardous state where the aircraft has lost engine power. | |
| Turbine assembly failure | and the loss of engine power hazardous state.<br><br>If more than one of these triggers appears in an accident, I group the triggers and refer to the group as a “rapid sequence of triggers”. |
| Exhaust system failure | |
| Propeller accessory drive failure | |
| Ignition system failure | |
| Bleed air system failure | |
| Fuel system failure | |
| Improper use of the fuel system | |
| Lubrication system failure | |
| Engine installation failure | |
| Reduction gear assembly failure | |
| Cooling system failure | |
| Turboshaft engine component failure | |
| Throttle/power control failure | |
| Fuel injection system contamination/failure | |
| Induction air system contamination/failure | |
| Inlet assembly failure | |
| Improper fuel grade | |
| Fuel contamination/exhaustion | |
| Carburetor heat control failure | |
| Improper reading from/failure of engine instruments | |
| Engine compartment failure | |
| Engine compressor stall/surge | |
| Engine pre-ignition/detonation | |
| Uncontained engine failure | |
| Engine accessories failure | |
| Improper use of throttle/powerplant controls | |
| Improper use of carburetor heat | |
| Improper use of deicing system | |
| Improper engine shutdown | |
| Deicing system failure | |
| Improper use of deicing system | |
| Unknown reasons | |

Similar to the loss of engine power state, there exists a clear relationship between the system failure state and the triggers associated with it. Table 34 shows the triggers for the system failure state.

Table 34 Triggers into the System Failure State

| System Failure State | |
|---|---|
| Hazardous state where an aircraft’s system(s)/component(s) have failed/malfunctioned. | |
| **Triggers into this state are** | **Notes** |
| Fuselage/wing failure | I identified these codes by searching the dictionary of triggers that indicated failure of a system or component. |
| Flight control surfaces/attachments failure | |
| Door/window failure/contamination | |
| Flight control system failure | |
| Stabilizer system failure | |

<table>
<tr><th colspan="2">System Failure State</th></tr>
<tr><td colspan="2">Hazardous state where an aircraft’s system(s)/component(s) have failed/malfunctioned.</td></tr>
<tr><td>Rotor drive system failure</td><td rowspan="27">Some triggers are common to the loss of engine power and system failure states. For example, improper use of the deicing system can potentially trigger pitot static tube malfunction (system failure), or a loss of engine power.<br><br>Snagging or entanglement of external load equipment can trigger a system failure or an inflight loss of control. In some accidents, the NTSB does not report a system failure, but indicates an inflight loss of control (with the snagging/entanglement code).<br><br>If more than one of these triggers appears in an accident, I group the triggers and refer to the group as a “rapid sequence of triggers”.</td></tr>
<tr><td>Rotor system failure</td></tr>
<tr><td>Rotorcraft flight control system failure</td></tr>
<tr><td>Airframe component failure</td></tr>
<tr><td>Electrical system failure</td></tr>
<tr><td>Hydraulic system failure</td></tr>
<tr><td>Improper use of electrical system</td></tr>
<tr><td>Improper use of hydraulic system</td></tr>
<tr><td>Navigation instrument failure</td></tr>
<tr><td>Rotorcraft flight control failure</td></tr>
<tr><td>Deicing system failure</td></tr>
<tr><td>Improper use of deicing system</td></tr>
<tr><td>Pneumatic system failure</td></tr>
<tr><td>Improper use of aerial application/external load equipment</td></tr>
<tr><td>Aerial application/external load equipment failure/entanglement</td></tr>
<tr><td>Entanglement of helmet</td></tr>
<tr><td>Improper use/failure of shoulder harness</td></tr>
<tr><td>Improper use/failure of seat belt</td></tr>
<tr><td>Entanglement of cargo restraints</td></tr>
<tr><td>Failure of rafts</td></tr>
<tr><td>Failure of furnishing equipment</td></tr>
<tr><td>Improper reading from/failure of engine instruments</td></tr>
<tr><td>Lubricating system failure/contamination</td></tr>
<tr><td>Propeller accessory drive failure</td></tr>
<tr><td>Exhaust system failure</td></tr>
<tr><td>Landing gear failure</td></tr>
<tr><td>Unknown reasons</td></tr>
</table>

Certain codes in the NTSB coding manual translate to triggers that have broad definitions, and can therefore trigger multiple hazardous states in a single accident. Improper inflight planning/decision-making is an example of a trigger that can be linked to multiple hazardous states in the same accident. Consider for example a sightseeing accident that occurred near Humuula, HI, in February 1994. The pilot encountered hazardous weather conditions, failed to maintain airspeed, and subsequently lost control of the aircraft and collided with terrain (NTSB ID: LAX94LA134). *Improper inflight planning/decision-making* is the only the trigger available from the accident report and can potentially trigger three hazardous states: intentional/inadvertent flight through poor weather, improper airspeed, and inflight loss of control. In this scenario, I assign improper inflight planning/decision-making as a trigger to all three hazardous states. Table 359 through 409 (in Appendix D) shows similar triggers that could be applied to multiple states in an accident.

Many rotorcraft accidents involved collision with terrain/objects. In some cases, these collisions were end states, while in other situations, colliding with (or clipping, hitting) objects/terrain caused the accident. To be able to differentiate between collisions that are end states and triggers in accidents, I defined four "clipping" triggers—clipping of object/terrain, clipping in midair, clipping of wing/rotor, and inflight fire/explosion (see Tables 21–24 for trigger definitions). Some accident reports indicate that the aircraft collided with an object/terrain before losing control. For example, in May 1994, the pilot of a Schweizer 269C lost control of the aircraft and collided with terrain near Hiram, GA (NTSB ID: ATL94LA100). The VFR-rated pilot inadvertently flew into IMC conditions, collided with trees, lost control of the aircraft, and impacted the terrain. When I apply the trigger definition to this accident sequence, the collision with trees translates to "clipping of object/terrain" trigger.

If the computer program cannot identify a trigger for each hazardous state in a particular accident, that accident is flagged for manual review.

Table 35 provides all the triggers that can cause the system to move to an inflight loss of control state.

Table 35: Triggers into the Inflight Loss of Control State

| **Inflight Loss of Control** | |
|---|---|
| A hazardous state that involves an unintended departure of an aircraft from controlled flight regime (FAA, 2016). | |
| **Triggers into this state are** | **Notes** |
| Improper use of cyclic | I searched for codes that were associated with controlling the aircraft. |
| Improper use of collective | |
| Improper compensation for winds | |
| Improper inflight planning/decision-making | |

<table>
<tr><th colspan="2">Inflight Loss of Control</th></tr>
<tr><td colspan="2">A hazardous state that involves an unintended departure of an aircraft from controlled flight regime (FAA, 2016).</td></tr>
<tr><td>Improper maneuvering</td><td rowspan="31">I excluded codes relating to system failure (with the exception of the entanglement triggers) and loss of engine power.<br><br>If no triggers were available from the accident report, I inferred triggers based on:<ul><li>Whether a system failure state preceded LOC If yes, I inferred the “impossible/reduced control authority” trigger.</li><li>Whether an improper autorotation/low RPM (engine not operational) /VRS state preceded LOC. If yes, I inferred the “incorrect use of collective/cyclic” trigger.</li><li>If the engine was operational, I inferred the “incorrect use of throttle/collective input”. Also, I used this trigger to indicate failed power recovery after a simulated autorotation.</li><li>If the helicopter experienced LTE, then I inferred “incorrect use of anti-torque pedal and cyclic”</li><li>If the pilot was in a disoriented state before LOC, I inferred the “no/failed recovery action after disoriented state” trigger. I used this trigger (and not improper remedial action) to be able to differentiate between codes that appeared in accident reports and those that I inferred.</li></ul></td></tr>
<tr><td>Improper aircraft handling</td></tr>
<tr><td>Improper use of rotorcraft flight controls</td></tr>
<tr><td>Improper use of tail rotor/anti-torque control</td></tr>
<tr><td>Not possible</td></tr>
<tr><td>Improper load jettison</td></tr>
<tr><td>Aerial application/external load equipment entanglement</td></tr>
<tr><td>Control interference</td></tr>
<tr><td>Relinquishing control</td></tr>
<tr><td>Failure to remove aircraft/rotor tie-down</td></tr>
<tr><td>Improper use of control friction</td></tr>
<tr><td>Improper trim setting</td></tr>
<tr><td>Disturbance by passenger</td></tr>
<tr><td>Improper remedial action</td></tr>
<tr><td>Improper use of flight controls</td></tr>
<tr><td>Incorrect action selected</td></tr>
<tr><td>Incorrect action performed</td></tr>
<tr><td>Incorrect sequence of actions</td></tr>
<tr><td>Delayed action</td></tr>
<tr><td>Lack of action</td></tr>
<tr><td>Forgotten/omitted action</td></tr>
<tr><td>Incomplete action</td></tr>
<tr><td>Unnecessary action</td></tr>
<tr><td>Not possible</td></tr>
<tr><td>Improper use of procedures/directives</td></tr>
<tr><td>Clipping of object/terrain</td></tr>
<tr><td>Clipping in midair</td></tr>
<tr><td>Incorrect use of throttle and/or collective input</td></tr>
<tr><td>Incorrect use of collective and/or cyclic</td></tr>
<tr><td>Incorrect use of anti-torque pedal and cyclic</td></tr>
<tr><td>Impossible/reduced control authority after system failure</td></tr>
<tr><td>No/failed recovery after disoriented state</td></tr>
</table>

| Inflight Loss of Control | |
|---|---|
| A hazardous state that involves an unintended departure of an aircraft from controlled flight regime (FAA, 2016). | |
| | If more than one of these triggers appears in an accident, I group the triggers and refer to the group as a "rapid sequence of triggers". |

Similarly, Tables 359 through 409 present the rules linking the different triggers and hazardous states.

# CHAPTER 5. ANALYZING HELICOPTER ACCIDENTS USING STATE-BASED ACCIDENT MODEL

In this chapter, I use three example questions to demonstrate the application and investigate the potential usefulness of the state-based model. I do one high-level analysis of the 6200 accidents in the database to identify the most frequent states and triggers—i.e., the states and triggers that are most likely to be associated with, or lead to, accidents. Next, I investigate the causal patterns associated with two of the most hazardous states—loss of control and improper autorotation.

## 5.1 Presence of Hazardous States and Triggers in Fatal and Non-fatal Accidents

Most efforts to reduce GA accidents focus on reducing fatal accidents. The argument made for focusing on reducing fatal accidents is that, since these accidents have the most severe consequences, we should first eliminate them. While this goal is worthy, it usually results in a narrow focus on investigating only fatal accidents, suggesting an underlying assumption that non-fatal accidents cannot provide insight into fatal accidents. Unfortunately, fatal GA accidents are often difficult to investigate. In many cases, it is hard to discern the reasons for an accident if the aircraft is extensively damaged or destroyed in a post-crash fire. Many fatal accidents have no survivors, making it impossible for investigators to gather information from interviews with pilots or occupants. Many rotorcraft do not have on-board flight data recorders (FDR) or "black boxes", making it challenging for investigators to reconstruct the reasons for fatal accidents. In contrast, non-fatal accidents, which account for the majority of accidents, offer the potential for deeper understanding because the aircraft is often not destroyed, and investigators can supplement their accident findings with pilot testimonies. Unfortunately, many investigations do not take advantage of this potential—in part because these accidents are not fatal and therefore do not warrant significant investigation resources.

In this section, I argue that data from non-fatal accidents can help us to better understand the causes of fatal accidents. To make my argument, I apply the state-based accident modeling approach to 6200 helicopter accidents that occurred in the US in 1982–2015. I identify the most frequent states (preflight, remaining, and end states) and triggers in accidents overall, and compare their presence in fatal and non-fatal outcomes[29]. I show that fatal and non-fatal accidents share many causes, thus deeper investigations of non-fatal accidents may help identify ways to reduce all types of accidents.

I begin by developing a measure of frequency that takes into account that states and triggers may repeat in a particular accident. Repeated occurrence of a state in an accident does not necessarily reflect greater importance. For example, the *prevailing/existing weather* hazardous state may be mentioned multiple times in an accident to describe various weather characteristics (e.g., tailwind, high density-altitude). Another example of repeated mention of a state in an accident involves *improper rotor RPM*—where the first instance refers to the rotor RPM being too high while the second instance is to indicate the RPM was too low. Therefore, we calculate the presence [cf. Sorenson and Marais, 2015] for each $Haz_j$ as the number of times that hazardous state was reported at least once in an accident, normalized by the total number of accidents:

[29] The work presented in this section is an extension of previous research (Rao and Marais, 2016).

$$presence\left(Haz_j \middle| Accident\right) = \frac{\sum_{i=1}^{n_{accidents}} TRUE\left(Haz_j \geq 1 \text{ AND } Accident_i\right)}{\#Accidents}$$

$$presence\left(Haz_j \middle| Fatal\ Accident\right) = \frac{\sum_{i=1}^{n_{fatal\ accidents}} TRUE\left(Haz_j \geq 1 \text{ AND } Fatal\ Accident_i\right)}{\#Fatal\ Accidents} \quad (6)$$

For example, the LOC hazardous state appears at least once in 2516 out of the 6200 accidents, thus its presence in rotorcraft accidents is 40.6%. The total presence of all the hazardous states generally does not sum to 100% because a given accident can involve multiple hazardous states. For example, an accident might involve both loss of control and inadequate rotor RPM hazardous states.

Between 1982 and 2015, there were 6200 helicopter accidents—16.2% were fatal and the remaining 83.8% were non-fatal[30].

Table 36: Comparison of the Ranking and Presence of End States in Fatal, Non-fatal, and Accidents Overall.

| **Description of End States** | **Presence in Accidents** | | |
|---|---|---|---|
| | **Overall** | **Fatal** | **Non-fatal** |
| Inflight collision with terrain/water/object | 45.2% | 79.0% | 38.6% |
| Hard landing | 19.2% | 2.5% | 22.4% |
| Roll over | 16.9% | 3.2% | 20.5% |
| On-ground collision with terrain/water/object | 2.7% | 1.1% | 3.0% |
| Forced/emergency landing | 1.9% | 0.2% | 2.2% |

[30] Similar to the classification in Chapter 3, I group all accidents that did not involve any fatalities as non-fatal accidents. The non-fatal category includes accidents that involved serious, minor, or no injuries.

Table 36 shows the top five end states in helicopters accidents overall in 1982–2015. The top five states are ranked based on their presence in accidents overall. The first column provides a description of the state, the second column shows the presence of the end state in accidents overall, and the third and fourth columns show the presence of end states in fatal and non-fatal accidents, respectively. The top five end states appeared in 84% of accidents. The other eight end states (see Table 27 in Chapter 4) accounted for the remaining accidents[31].

Not surprisingly, 45.2% of the accidents had inflight collision with terrain/water/object as the end state (flights must end on the ground/water). The deadly nature of this end state is highlighted by its high presence (79%) in fatal accidents.

The hard landing end state has the second highest presence (19.2%) in accidents overall, as shown in the second row of Table 36. Accidents that ended in hard landings were generally survivable, as indicated by the high presence of this end state in non-fatal accidents. Many accidents that involved improper autorotation ended in hard landings.

Rollovers occur when the helicopter exceeds a critical roll/bank angle while one of the skids (landing gear wheels) is in contact with the ground. Rollovers appeared third most frequently in accidents overall. Similar to hard landings, accidents that ended in rollovers usually did not result in death.

Table 37: Comparison of the Presence of Preflight states in Fatal, Non-Fatal, and Accidents Overall.

| **Description of Preflight States** | **Presence in Accidents** | | |
|---|---|---|---|
| | **Overall** | **Fatal** | **Non-fatal** |
| Prevailing/existing weather and light state | 17.7% | 19.4% | 17.4% |

[31] 6% of the accident did not have a permissible end state. See discussion regarding non-permissible end states in Chapter 3.

| Description of Preflight States | Presence in Accidents | | |
|---|---|---|---|
| | Overall | Fatal | Non-fatal |
| Preflight mechanical issues | 13.9% | 17.1% | 13.2% |
| Qualification/lack of experience | 6.4% | 11.1% | 5.5% |
| Improper supervision | 4.0% | 1.6% | 4.4% |
| Overconfidence/lack of confidence | 1.1% | 3.0% | 0.8% |

Table 37 shows the top five preflight hazardous states in helicopter accidents between 1982 and 2015. Not all poor weather accidents need necessarily involve intentional/inadvertent flight through poor weather. While flight in the prevailing weather (or light) state (e.g., high density altitude, tailwind, or glare) can be considered less hazardous (than, say, VFR flight into IMC), the prevailing weather and light conditions could still play a role in the accident. This state has the highest presence (17.7%) in accidents overall.

Preflight mechanical issues appeared in 13.9% of accidents overall. Flights that began with preflight mechanical issues had a higher presence in fatal accidents (17.1%) compared to non-fatal cases (13.2%), highlighting the importance of proper maintenance and preflight checks.

6.4% of accidents began with pilots who lacked relevant experience with regard to the aircraft or operating environment. The presence of lack of experience is almost twice as high in fatal accidents as in non-fatal accidents, suggesting that inexperienced pilots are more likely to get into situations that result in fatalities.

Table 38: Comparison of the Presence of Intermediary states in Fatal, Non-Fatal, and Accidents Overall.

| Description of Intermediary States | Presence in Accidents | | |
|---|---|---|---|
| | Overall | Fatal | Non-fatal |
| Inflight loss of control | 40.6% | 60.3% | 36.7% |

| Description of Intermediary States | Presence in Accidents | | |
|---|---|---|---|
| | Overall | Fatal | Non-fatal |
| Loss of engine power | 26.0% | 14.7% | 28.2% |
| Improper altitude/clearance | 15.8% | 23.8% | 14.0% |
| System failure | 13.1% | 17.7% | 12.2% |
| Improper autorotation | 9.8% | 7.6% | 10.3% |

Table 38 shows the top five intermediary states (i.e., states that are neither end states, nor preflight hazardous states). Inflight loss of control (LOC) was the top-ranked hazardous state, appearing in 40.6% of helicopter accidents in 1982–2015. Accidents involving loss of control often had severe consequences, as indicated by a high presence of 60.3% in fatal accidents, versus 36.7% in non-fatal accidents. The presence of LOC in over a third of the non-fatal accidents (36.7%) provides potential opportunities to learn more about the causes for LOC by interviewing pilots/passengers who survived the LOC accidents.

Loss of engine power is the second-ranked hazardous state in helicopter accidents, with a presence of 26.0% in accidents overall. Pilots are trained to perform autorotative landings if they experience a loss of engine power during flight. Many pilots are able to recover successfully, as indicated by the higher presence of 28.2% in non-fatal accidents.

The improper altitude/clearance hazardous state appeared third most frequently in helicopter accidents overall. Failure to maintain proper altitude/clearance from terrain/objects often results in inflight collisions with terrain/object (end state) or clipping terrain/object, which can potentially trigger an LOC state. Maintaining altitude is one of the key elements to a successful autorotative landing. Misjudged or inadequate altitude during autorotations can potentially result in accidents.

System failure appeared in 13.1% of accidents overall. Failure of critical aircraft control systems (e.g., cyclic control) can often render the helicopter uncontrollable. The high presence in fatal accidents (17.7%) compared to non-fatal outcomes (12.2%) suggests that flights with inflight system failures were more likely to end in fatalities.

Similar to the previous calculations (see Eq. 6), the presence of a $Trigger_k$ is given by the number of times that trigger event was cited at least once in an accident (fatal, and non-fatal), normalized by the total number of (fatal, and non-fatal) accidents:

$$presence(Trigger_k |\ Accident) = \frac{\sum_{i=1}^{n\ accidents} TRUE(Trigger_k \geq 1 |\ Accident_i)}{\#Accidents}$$

$$presresence(Trigger_k | Fatal\ Accident) = \frac{\sum_{i=1}^{n_{fatal\ accidents}} TRUE(Trigger_k \geq 1 | Fatal\ Accident_i)}{\#Fatal\ Accidents} \tag{7}$$

For example, the *inflight planning/decision* trigger appears at least once in 100 out of the 1005 fatal accidents, thus its presence in fatal accidents is 14.3%. Similarly, it appears at least once in 422 out of 5195 non-fatal accidents, thus its presence in non-fatal accidents is 7.8%.

Note that the NTSB assigned the "*25000: Reason for occurrence undetermined*" subject code when the reason for an occurrence was unknown—in 11.4% of fatal accidents and 9.4% of non-fatal accidents. Although this code is one of the most frequently cited, I do not include it in the ranking of top triggers because it does not provide any information on the actual cause in an accident.

Table 39: Comparison of the presence of triggers in Fatal, Non-Fatal, and Accidents Overall.

| Description of Preflight States | Presence in Accidents | | |
|---|---|---|---|
| | Overall | Fatal | Non-fatal |
| Improper maintenance | 10.8% | 11.0% | 10.2% |
| Improper inflight planning/decision-making | 8.9% | 14.3% | 7.8% |
| Improper use of procedures/directives | 7.5% | 10.0% | 7.0% |
| Improper preflight planning | 7.0% | 7.7% | 6.8% |
| Rotor drive system failure | 6.5% | 6.6% | 6.5% |

Table 39 shows the top five triggers associated with helicopter accidents in 1982–2015. The improper maintenance trigger has the highest presence overall. Improper maintenance actions include errors (slips, lapses, or mistakes) or violations (disregarding directives/procedures). Improper maintenance can trigger a preflight mechanical issue (which is the second-ranked preflight hazardous state). Improper maintenance often affects key helicopter systems such as the rotor system and rotor drive system (Rao et al., 2016).

Improper inflight planning/decision-making is ranked second based on presence in accidents overall. It has the highest presence in fatal accidents (14.3%). The coding manual and accident reports provide little information on the exact nature of poor decisions made by pilots. A possible reason for the high presence of improper inflight planning/decision-making could be that investigators did not have enough information to make a more accurate determination of what went wrong in accidents (and chose improper inflight planning/decision-making instead).

Improper use of procedures or directives was more likely to appear in fatal than non-fatal accidents. This trigger represents situations where the pilots/maintenance personnel had access to sufficient information/procedures, and chose to disregard or failed to use them correctly.

As part of their training, pilots are instructed to complete a thorough *preflight plan* prior to departure. The preflight plan includes an airworthiness check, weather briefing, and consulting navigation charts to plot a flight path and make note of terrain or obstacles. Failure to carry out or complete a preflight plan can put the flight in a hazardous state before departure. For example, on a snowy evening in January 1991, an MBB BK-117B1 crashed into terrain while returning from a medevac mission near Sonestown, PA (NTSB ID: NYC91FA067). The resulting crash killed the pilot and three other occupants. The NTSB used radar data and flight data recovered from the helicopter to reconstruct the flight path and altitude. Their investigation revealed that impact with a mountain ridge occurred at 2440 ft. MSL, while the ridge was 2520 ft. MSL with 40 ft. high trees. The NTSB concluded that the pilot's preflight planning did not consider the ridge. In this accident, it is likely that the pilot took no evasive action because he had limited knowledge of the impending collision with terrain.

The *rotor drive system*, as the name indicates, is responsible for driving the main rotor and tail rotor in a helicopter. Failure of any component in this system triggers a system failure hazardous state. Recovering directional control of the helicopter, and performing a safe autorotative landing becomes difficult after a rotor drive system failure. The almost equal presence in fatal and non-fatal suggests that this trigger is equally likely to appear in both fatal and non-fatal outcomes.

I began this section by arguing that we can use non-fatal helicopter accident data to potentially better understand the causes for fatal accidents (and accidents overall). To see if there is potential to learn from non-fatal accidents, I used the state-based approach to identify the top hazardous states and triggers in accidents overall. Then, I compared the presence of these states and triggers in fatal and non-fatal accidents. The results from the analysis suggest that we can learn from non-fatal accidents to improve rotorcraft safety.

Poor aeronautical decision-making (ADM) is a feature of both fatal and non-fatal GA accidents. Poor *inflight planning/decision-making* was the top trigger in fatal accidents. While this trigger suggests that an incorrect action or improper setting chosen by the pilot led to the hazardous state, it provides little information about the actual action taken during flight. Since this trigger is important in fatal accidents, and occurs frequently in non-fatal accidents, we have an opportunity to learn much more about it, and potentially prevent both fatal and non-fatal accidents. One way we could learn from these accidents is by interviewing pilots or survivors about the incorrect actions that resulted from bad decisions, and also the circumstances that might have resulted in poor decisions. The interviews might also lend insight into pilots' risk perception, confidence in their abilities, and assessment of situations. Another avenue that could potentially improve our understanding of bad decisions includes analyzing flight data recorder (FDR) data in fata (and non-fatal) accidents. While the number of GA aircraft with FDRs is limited, recent efforts to improve GA safety using flight data records could help understand pilot decision-making.

*Improper maintenance* was the second-ranked trigger in fatal helicopter accidents, and had a similar presence in non-fatal accidents. This trigger puts that system in a *preflight mechanical issue* state (which happens to be the second most frequent preflight hazardous state). In many cases, system failures that often follow preflight mechanical issues can render aircraft difficult (if not impossible) to control. Paying closer attention to the kinds of mistakes or violations by maintenance personnel, and the affected systems, can help potentially prevent future preflight mechanical issues.

*Improper preflight planning* puts the flight at risk (of an accident) before departure. The act of not doing/completing a preflight plan not only puts the rotorcraft in a preflight hazardous state, but also indicates pilots' hazardous attitudes prior to flight. Not consulting weather briefings, not noting terrain/objects in flight path, and disregard for preflight procedures were present in both fatal and non-fatal accidents. Similar presence in non-fatal accidents could help learn lessons that include: (1) reasons for not completing a preflight plan; (2) key preflight parameters that were missed (e.g., aircraft weight and balance, fuel level); and (3) actions (or inactions) due to lack of information (that pilots might have acquired by following preflight procedure).

## 5.2 Analysis of Inflight Loss of Control Accidents

Analyses of GA accident data by several researchers and safety teams generally arrive at a common conclusion—*Inflight loss of control (LOC) is the top cause for GA accidents.* Harris et al. (2000) analyzed over 8000 helicopter accidents that occurred during 1963–1997. They found that LOC was the cause for 625 out of 5371 (approximately 12%) accidents involving civilian helicopters. In 2010, the US Joint Helicopter Safety and Analysis Team (US JHSAT) selected and analyzed 523 helicopter accidents for 2000, 2001, and 2006 (they do not specify the reasons for selecting the aforementioned years for their analysis). In their analysis, they found that inflight loss of control was the top cause—accounting for over 41% of the accidents in their dataset (US JHSAT, 2011). In a related study, the US Joint Helicopter Implementation Measurement Data Analysis Team (US

JHIMDAT) analyzed 415 helicopter accidents that occurred between 2009 and 2011 (US JHIMDAT, 2014). Their analysis showed that inflight loss of control was not only the top cause, but accounted for a greater proportion of accidents when compared to the US JHSAT study (47.5% compared to 41%). A 2012 study by the Government Accountability Office (GAO) to improve GA safety termed LOC as the most frequent "defining event" in GA accidents. In fact, recently, we (Rao and Marais, 2015) analyzed 5051 helicopter accidents that occurred in 1982–2008, and identified LOC as the most frequent single-node occurrence chain.

While all of these studies indicated that LOC was the top reason for GA (fixed wing and helicopter) accidents, they did not provide any information on "why" the accident-aircraft (and pilot) experienced loss of control. One of the potential reasons for the limited understanding of LOC causation could be due to the setup of the NTSB accident coding system. In this section, I use the state-based approach to: (1) check if we are correctly counting accidents that involved LOC; and (2) potentially identify the gaps in our understanding of the causes (or the "why") for helicopter accidents that involved LOC. Then, I compare the results from this analysis with those of a conventional analysis using only the NTSB codes.

### 5.2.1 Conventional Analysis of LOC Accidents from NTSB Database

In this section, I carry out a conventional analysis of the NTSB accident database. I identify LOC accidents using the NTSB occurrence codes, and determine the top causes and contributing factors for LOC using the subject codes. Since the accident dataset spans a 32-year period that uses multiple NTSB accident coding systems (pre- and post-2008 coding systems), I present the results from each of these coding systems separately.

#### 5.2.1.1 LOC Accidents in 1982–2008

I begin by identifying the accidents that involved LOC. In the pre-2008 system, the NTSB specifies the occurrence "250: Loss of control inflight" for LOC accidents. I identified 1403 (26.8%) accidents that involved LOC, with 22.5% of them being fatal.

As mentioned in Chapter 3, the NTSB uses subject codes and modifiers to describe the various events in an accident. In each accident, they classify some of the subject codes as causes or contributing factors, and the remaining codes as findings (that are neither causes nor factors). Table 40 shows the top five subject codes in a causal role.

Table 40: Top Causes for LOC Accidents (pre-2008)

| **Subject Codes that were causes for LOC** | **Presence in Accidents** |
|---|---|
| 24566: Aircraft control | 16.6% |
| 24558: Rotor RPM | 9.3% |
| 24539: Directional control | 8.6% |
| 24010: Inflight planning/decision-making | 7.0% |
| 25000: Reason for occurrence undetermined | 6.3% |

Unsurprisingly, the *24566: Aircraft control* subject code was cited most often, appearing at least once in 16.6% of fatal LOC accidents. In 86% of cases, this subject code was modified with "not maintained"; in other words, (one of) the recorded causes for inflight loss of control was "not maintaining aircraft control"!

The 24539: *Directional control* subject code appeared at least once in a causal role in 8.6% of LOC accidents. Accidents that blamed *Directional control* point to the pilot's inability to maintain lateral directional authority over the rotorcraft. Pilots in these accidents often encountered situations such as loss of tail rotor effectiveness during hover, yaw and roll exceedances while compensating for strong crosswinds, or loss of directional control due to tail rotor system failure. The directional control code, similar to aircraft control, was frequently modified by “not maintained”. This code (like 24566: Aircraft control) provides little information about the cause for LOC.

Maintaining rotor RPM is critical to safe rotorcraft flight. The FAA helicopter flying handbook emphasize this point by stating that “RPM is life”. In LOC accidents that occurred in 1982–2008, 24558: Rotor RPM appeared as the second most frequent cause (9.3% of LOC accidents). Failure to maintain rotor RPM can result in the onset of blade stall and subsequent LOC. If all the blades stall, the outcome is usually fatal (FAA, 2016c). The pilot can correct rotor RPM by altering the throttle setting, or appropriate collective and cyclic control inputs.

*24010: Inflight planning/decision-making* was a cause in 7.0% of LOC accidents. Generally, the coding system and accident reports provide little information on the exact nature of poor decisions made by pilots. In many LOC accidents, the NTSB does not record the specific actions following a poor decision by the pilot.

Table 41: Top Contributing Factors for LOC Accidents (pre-2008)

| **Subject Codes that were contributing factors for LOC** | **Presence in Accidents** |
|---|---|
| 20000: Weather condition | 33.1% |
| 19200: Terrain condition | 13.5% |
| 20200: Object | 7.8% |
| 20100: Light condition | 4.6% |
| 34333: Lack of total experience in type of aircraft | 2.4% |

Table 41 shows the top five contributing factors for LOC accidents. Four out of the top five contributing factors (weather condition, terrain condition, object, and light condition) provide additional information about the environment in which the accident occurred.

Over a third of the LOC accident reports (33.1%) cited 2000: Weather conditions as a contributing factor to the accident. Accompanying modifiers for this code include “rain”, “fog”, “tailwind”, and “gust”. The modifiers provide additional information about the nature of weather in LOC accidents.

The NTSB used *19200: Terrain condition* to provide additional information about the topography of the area. The nature of terrain played a key role in the outcome (e.g., fatal vs. non-fatal) of many LOC accidents. For example, an LOC accident over grassy vegetation might be more survivable than an accident that occurs near mountainous terrain.

Similar to the subject code that describes the weather condition, 20100: *light condition* indicates the nature of ambient lighting that prevailed at the time of the LOC accident. Modifiers for this code included “dark night”, “sun glare”, “night”, and “dusk”.

#### 5.2.1.2 LOC Accidents in 2008–2015

I used the occurrence code *240: Loss of control inflight* to identify LOC accidents recorded under the post-2008 accident coding system. I identified 226 LOC accidents, with 20% of them being fatal.

Table 42: Top Causes for LOC Accidents (post-2008)

| **Subject Codes that were causes for LOC** | **Presence in Accidents** |
|---|---|
| 02063040XX: Use of equipment/info—Aircraft control | 49.1% |
| 01062000XX: Performance/control parameters (general) | 18.6% |
| 01062052XX: Performance/control parameters—Prop/rotor parameters | 13.7% |
| 01062020XX: Performance/control parameters—Directional control | 11.5% |
| 02041015XX: Action-Incorrect action performance | 7.5% |

Table 42 shows the top five causes for LOC accidents in 2008–2015. Similar to the causes in the pre-2008 accidents, the NTSB frequently attributed not maintaining control (*02063040XX: Use of equipment/info-Aircraft control*) and failing to maintain directional control (*01062020XX: Performance/control parameters-Directional control*) among the top causes for LOC. In addition to these two codes, they used a generic code, *01062000XX: Performance/control parameters (general),* to suggest that the pilot lost control of the aircraft. These codes can be simply thought of as tautologies for LOC, and not necessarily as causes.

Failing to maintain rotor RPM is ranked third among the top causes for LOC accidents, appearing at least once in 13.7% of accidents. In some cases, pilots fail to maintain rotor RPM during autorotative landings. The FAA helicopter flying handbook states the following while suggesting measures to be taken by the pilot in the event of an engine failure: "*By lowering the collective pitch, which must be done immediately in case of an engine failure, lift and drag are reduced, and the helicopter begins an immediate descent, thus producing an upward flow of air through the rotor system. This upward flow of air through the rotor provides sufficient thrust to maintain rotor rpm throughout the descent*". Failure to maintain rotor RPM can result in a failed autorotation, loss of control, and subsequent hard landing.

*02041015XX: Action-Incorrect action performance* appears at least once in 7.5% of LOC accidents. This code, as the name suggests, indicates incorrect action by the pilot, which potentially resulted in LOC.

Table 43: Top Contributing Factors for LOC Accidents (post-2008)

| **Subject Codes that were contributing factors for LOC** | **Presence in Accidents** |
|---|---|
| 02041025XX: Action-Delayed action | 3.1% |
| 02041515XX: Info processing/decision—Understanding/comprehension | 1.3% |
| 02041520XX: Info processing/decision—Decision making/judgment | 1.3% |
| 03021017XX: Terrain-Sloped/uneven | 1.3% |
| 01022701XX: Flight control system-control column section | 0.9% |

Table 43 shows the top contributing factors for LOC accidents. In contrast to the pre-2008 system, the top five contributing factors accounted for only 10.2% of the LOC accidents. Some of the reasons for the lower presence of the top five contributing factors could be due to: (1) a larger (and potentially better) set of codes for the NTSB investigators to choose from; or (2) just that there have been fewer accidents recorded under the post-2008 system.

In the post-2008 system, the NTSB frequently use the newly introduced *02041025XX: Action-Delayed action* code to indicate that delayed action (e.g., control inputs) was a contributing factor in LOC accidents.

The codes corresponding to decision-making/judgment and comprehension/understanding appeared in the top-three contributing factors (In 1982–2008, the NTSB listed inflight planning/decision-making as one of the top causes).

The code *01022701XX: Flight control system-control column section* corresponds to the mechanical failure of the flight control column (also referred to as the yoke). The failure of the control column generally renders the aircraft uncontrollable.

### 5.2.2 State-based Analysis of LOC Accidents

In this section, I present the results from the state-based analysis of LOC accidents. Similar to the conventional analysis, I begin by identifying LOC accidents from the set of 6200 helicopter accidents that occurred in the US in 1982–2015. After applying the definition for the LOC state (see Table 14 in Chapter 4), I identified 2520 accidents that involved the LOC state—an increase of 891 accidents compared to 1629 identified using the conventional database analysis. The larger set of accidents using the state-based approach can be attributed to the definition for this state, which involves a combination of subject codes, occurrences, and phase of flight code (compared to the single occurrence that is used in a conventional analysis of the database). As mentioned in Chapter 4, the NTSB uses some of these codes interchangeably when referring to LOC in accidents—the definition for the LOC state in the state-based approach takes into account the different codes used by the NTSB to represent LOC.

Triggers were available from the accident database for 42.2% of the 2520 accidents. Table 44 shows the top five triggers for the LOC state. Using an expression similar to Eq. 2, I calculated the presence for each trigger as a proportion of the number of times a trigger appears at least once in an LOC accident, to the total number of LOC accidents (2520 accidents).

Table 44: Top Triggers from the Database for the LOC State.

| **Triggers from Database** | **Presence in Accidents** |
|---|---|
| Inflight planning/decision-making | 10.3% |
| Not possible | 8.9% |
| Improper remedial action | 6.9% |
| Improper maneuvering | 3.5% |
| Improper compensation for wind | 3.2% |

Comparing the top triggers in Table 44 with the top causes and factors for LOC (in Tables 40 through 44) reveals that only inflight planning/decision-making is common across both the state-based and conventional analyses. As mentioned earlier, the planning/decision-making trigger can be linked to multiple hazardous states in an accident.

In some accidents, the pilot was unable to control the aircraft owing to the failure of on-board systems, or was in a flight regime that made it impossible to control the aircraft. The "not possible" trigger captures these situations and appears in 8.9% of LOC accidents.

Improper remedial action is ranked fourth, appearing at least once in 6.9% of LOC accidents. This trigger does not provide any insight into the type of remedial action (e.g., lowered collective) that was not executed correctly.

Pilots are trained to maintain directional control using the anti-torque pedals that affect the thrust produced by the tail rotor. Improper compensation for wind can trigger a loss of directional control. The high presence of this trigger (which provides specific information regarding pilot action) highlights the tendency for helicopter pilots to misjudge wind intensity while applying anti-torque pedals.

Next, I discuss the remaining 57.8% (1457 out of 2520) of LOC accidents that did not have triggers in the accident reports. In these cases where it is not possible to identify the necessary triggers from the accident report, I infer triggers based on the rules linking the LOC state and triggers (see Table 14 in Chapter 4 for a description of the rules). Table 45 shows the inferred-triggers for the LOC state.

Table 45: Inferred Triggers for the LOC State

| **Triggers that are inferred** | **Presence in Accidents** |
|---|---|
| Clipping of object/terrain | 16.7% |
| Limited/no control after system failure | 7.7% |

| **Triggers that are inferred** | **Presence in Accidents** |
|---|---|
| Improper use of throttle and/or collective | 3.1% |
| Improper use of collective and cyclic | 3.1% |
| Improper use of anti-torque control | 2.8% |

1874 out of 2520 (74.3%) LOC accidents involved collision with terrain/water or object. From a conventional analysis of the database, it is not possible to determine if these collisions caused the accident or were end states. Using the grammar linking states and triggers (see Table 21 in Chapter 4), I inferred the "clipping" trigger in 16.7% of LOC accidents. LOC accidents involving this trigger occurred when pilots failed to maintain clearance from an object/terrain, resulting in "clipping" the object/terrain. Consider for example the fatal LOC accident that occurred near Umpqua, OR, during an external load operation (NTSB ID: SEA95LA10). During the mission, the pilot failed to maintain clearance from an object (in this case, a tree). He "clipped" the object and subsequently lost control of the aircraft, and collided with the terrain.[32]

Limited or no control after system failure is the top inferred trigger, with a presence of 7.7% in LOC accidents. I inferred this trigger when the LOC accident involved the system failure state. Consider a 1996 accident that occurred near Gretna, VA (NTSB ID: IAD96LA094). During flight, the main rotor drive shaft failed, jammed the flight controls, and triggered a system failure state. The pilot had limited control authority over the aircraft and subsequently entered the LOC state. He attempted an autorotation, but collided with the terrain. Similarly, I inferred this trigger in LOC accidents that did not have trigger information in the accident reports.

[32] To ensure the correct working of the clipping object/terrain rule, I read multiple accident reports that were identified by this rule. The NTSB IDs for a sample of these accident reports are: SEA96LA070, FTW96LA274, FTW96TA383, and CEN09CA339.

Improper use of throttle and/or collective is the second most frequent inferred trigger, appearing in 3.1% of LOC accidents. I inferred this trigger only when the accident: (1) did not involve loss of engine power; and (2) the low RPM state preceded LOC. Describing how to recover from a low RPM state, the FAA's helicopter flying handbook states that "While in flight, RPM may be regained by lowering the collective slightly and increasing the RPM" (of the engine) (FAA, 2016c).

Improper use of collective and cyclic triggered the LOC state in 3.1% of accidents, as shown in Table 10. I inferred this trigger when an improper autorotation (not maintaining RPM after loss of engine power) appeared before LOC in the accident sequence. A recent addendum to the helicopter flying handbook states that during an autorotation, the pilot must apply simultaneous aft cyclic (along with collective pitch) to prevent lowering of the nose and associated loss of RPM (FAA, 2016d).

The improper use of anti-torque control trigger appears in 2.8% of LOC accidents. As mentioned earlier, failure to compensate for winds using the anti-torque pedal can trigger a loss of directional control. I inferred this trigger when the aircraft experience a loss of tail rotor effectiveness (LTE) before LOC. The pilot's failure to effect anti-torque/tail rotor control after LTE can result in a loss of directional control.

In some accidents, the NTSB mentioned that pilots in a spatially disoriented state lost control of the aircraft. In such cases, I inferred the "no action after being disoriented" trigger. This trigger appears at least once in 1.7% of LOC accidents.

Inferring triggers for LOC accounted for 17.4% or 440 LOC accidents, leaving us with a deficit of 600 accidents (23.8% of all LOC accidents) which did not have any triggers—

neither from the database, nor inferred. The computer program stores these accidents for future review.

### 5.2.3 Summary

In sections 5.2, I conducted a conventional analysis of NTSB database and identified the top causes and contributing factors for LOC. Then, I applied the state-based approach to identify the top triggers for the LOC state. Table 46 compares and summarizes the results from both analyses.

Table 46: Top Triggers that are inferred for the LOC State

| | **Conventional Analysis** | **State-based Analysis** | **Remarks** |
|---|---|---|---|
| Number of accidents identified | 1629 | 2520 | The larger set of accidents using the state-based approach can be attributed to the definition for this state, which involves a combination of subject codes, occurrences, and phase of flight code (compared to the single occurrence that is used in a conventional analysis of the database). |
| Top cause | Aircraft control (16.6%) (pre-2008) | - | The subject codes for aircraft control appeared as the top causes for LOC accidents recorded in the pre- and post-2008 coding systems. The presence of this subject code provides no insight into why LOC happened. |
| | Aircraft control (49.1%) (post-2008) | | |
| Top factor | Weather condition (33.1%) (pre-2008) | - | The weather condition code appeared as the top contributing factor for LOC accidents in 1982–2008. It indicates that weather played a role in the accident. The use of the new coding system by the NTSB revealed that delayed action |

| | Conventional Analysis | State-based Analysis | Remarks |
|---|---|---|---|
| | Delayed action (3.1%) (post-2008) | | by the pilot was the top contributing factor. While this code provides some information about the nature of the action, it does not provide specifics (e.g., lowering collective). |
| Top trigger from database | - | Inflight planning/decision-making (10.3%) | This trigger is not informative and provides little insight into the mistakes/decisions taken by pilots. |
| Top inferred trigger | - | Clipping of object/terrain (16.7%) | LOC accidents involving this trigger occurred when pilots failed to maintain clearance from an object/terrain, resulting in "clipping" the object/terrain |

A comparison of the results from the conventional database analysis and state-based approach revealed some key differences. Results from the conventional analysis provide little insight into the causal mechanism for LOC. For instance, listing "aircraft control/directional control not maintained" as the top cause does not help further our understanding of LOC accidents.

Results from the state-based analysis showed that pilots' tendency to clip objects frequently triggered LOC. The high presence of this trigger is not surprising, considering the nature of helicopter operations (often in proximity to terrain/objects). However, this information was not available from a conventional analysis of the database because it does not take into the account the sequence of states in an accident; i.e., the state-based approach helps differentiate between a collision with terrain/object that is an end state, or a trigger in the accident. Further, the frequent occurrence of LOC after system failure highlights the importance of aircraft maintenance and preflight checks.

The frequent citing of inflight planning/decision-making (in both approaches) could be due to a lack of information available to investigators about the actual reason for LOC. I argue that the use of this code is not helpful; on the contrary, it potentially takes away analysts' and operators' focus from specific triggers/causes such as not maintaining tail rotor control.

## 5.3 State-based Analysis of Improper Autorotation

An autorotation is a state of helicopter flight where the helicopter's main rotor blades are driven by aerodynamic forces, and not by the engine. Pilots are instructed to perform an autorotative descent as part of numerous emergency procedures (FAA, 2016c).

As mentioned in Chapter 3, the NTSB's use of the autorotation code in accidents does not always distinguish between a successful and improper autorotation. Also, the accident codes often do not indicate the reasons for improper autorotations. In this section, I provide background on accidents in the database that involved autorotations. Then, I apply the state-based approach to potentially better identify improper autorotations, and understand the reasons behind improper autorotations.

### 5.3.1 Background on Accidents that Involved Autorotations

Analyzing 6200 helicopter accidents that occurred in the US in 1982–2015 reveals that 24.2% of accidents involved autorotations. I begin my discussion of autorotation accidents recorded under the pre-2008 system. Later in this section, I briefly discuss autorotation accidents recorded in the post-2008 system.

In the pre-2008 system, the NTSB used the subject code *24520: Autorotation* (accompanied by 25 different modifiers) to identify 1277 accidents that involved autorotative descent. Table 47 shows the top five modifiers associated with the autorotation code.

Table 47: Top Modifiers for the NTSB Autorotation Code (pre-2008)

| **Description of Modifiers** | **Presence in Autorotation Accidents** |
|---|---|
| 3135: Performed | 48.2% |
| 3118: Initiated | 17.5% |
| 3100: Attempted | 10.8% |
| 3109: Improper | 4.9% |
| 3001: “Blank” modifier | 4.3% |

Three of the top five modifiers only suggest that pilots “performed”, “initiated”, or “attempted” to Autorotate. The frequent use of these modifiers with the autorotation code may lead one to incorrectly conclude that a majority of autorotations did not involve any problems. The “improper” code appeared only in 4.9% of accidents that involved autorotations. Table 48 provides a distribution of the top modifiers that suggested improper autorotation.

Table 48: Top Modifiers that suggested Improper Autorotation (pre-2008)

| **Description of Modifiers** | **Presence in Autorotation Accidents** |
|---|---|
| 3109: Improper | 4.9% |
| 3131: Not possible | 3.1% |
| 3120: Misjudged | 1.7% |
| 3128: Not performed | 1.0% |

| **Description of Modifiers** | **Presence in Autorotation Accidents** |
|---|---|
| 3104: Delayed[33] | 0.9% |

The top modifiers that suggest improper autorotation accounted for only 11.7% of the 1277 autorotation accidents (in fact, including the all the modifier that suggested improper autorotation accounted for only 13.5% of accidents). Further, the autorotation code does not provide any additional insight into the cause for improper autorotations (e.g., did the pilot not maintain RPM during the autorotative descent?).

The post-2008 coding system further obscures the role of autorotations in accidents. The NTSB uses a phase of flight code “601: Autorotation” to indicate that the accident involved an autorotation. This code is not accompanied by any modifiers, making it impossible to determine if accidents involved improper autorotations. There were 227 autorotation accidents in the post-2008 system.

### 5.3.2 State-based Analysis of Autorotation Accidents

In this section, I present the results from the state-based analysis of autorotation accidents. Specifically, I want to identify accidents that involved “improper” autorotations. As mentioned in Chapter 4, the key elements to a successful autorotation are: maintaining (1) rotor RPM, (2) airspeed, (3) altitude, (4) descent profile/rate, (5) distance from the landing site, and (6) executing a correct flare/level-off. Thus, I classify an autorotation as “improper”

[33] The other modifiers that suggested improper/incorrect autorotations are: “3115: inadequate”, “3122: not attained”, “3140: uncontrolled”, “3136: poor”, “3145: restricted”, “3011: not obtained”, “3030: not successful”, “3110: improper use of”, “3125: not identified”, “3127: not maintained”, “3137: premature”, and “3144: discontinued”.

if one or more of these key elements are not maintained. Table 16 (Chapter 4) provides the definition for the improper autorotation state.

I begin by identifying improper autorotation accidents from the set of 6200 helicopter accidents that occurred in the US in 1982–2015. After applying the definition for an improper autorotation, I identified 632 accidents that involved the improper autorotation state—an increase of 458 accidents when compared to the 174 obtained using NTSB modifiers. Table 49 shows the presence of the key elements in improper autorotations.

Table 49: Distribution of Key Elements in Improper Autorotations

| **Description of Key Elements** | **Presence in Autorotation Accidents** |
|---|---|
| Improper RPM | 37.5% |
| Improper flare | 28.6% |
| Improper altitude | 11.7% |
| Improper descent | 11.6% |
| Improper airspeed | 5.4% |
| Improper distance from landing site | 1.7% |
| Operating in the hazardous region of the height-velocity curve | 1.7% |
| Improper level-off | 1.6% |

Failure to maintain RPM appeared at least once in 37.5% of accidents that involved improper autorotations. Consider an instructional accident that occurred near Englewood, CO, in March 1999 (NTSB ID: DEN99LA058). The student and flight instructor were practicing autorotations when the flight instructor failed to maintain rotor RPM. He was not able to perform a power recovery (during which the pilot roll-up the throttle and lowers the collective to gain RPM), and landed hard. While the subject and modifier codes in the accident report indicate that the “autorotation was performed”, the state-based approach provides a more complete picture of the accident. Reading the narrative for the accident reveals that "*the flight instructor allowed the RPM to decay during the autorotation*"—confirming the findings from the state-based approach.

In preparation for landing, the pilot decelerates the helicopter with the use of appropriate aft cyclic control. During this "flare" state, the pilot needs to avoid a nose-high and tail-low attitude, which can result in a tail strike. Table 49 shows that failure to perform a proper flare appeared in 28.6% of improper autorotation accidents.

Not maintaining the proper descent angle or descent rate can result in an improper autorotation. 11.7% of improper autorotation accidents involved improper descent. During descent, pilots should carefully adjust cyclic control to maintain the correct glide attitude, and adjust the collective pitch to maintain RPM—any sudden collective movements can trigger an improper autorotation.

In some cases, the NTSB mentions the height-velocity curve (also known as the Deadman's curve) in the context of autorotation accidents. This curve shows the heights and airspeeds above the ground which, in the case of a loss of engine power or system failure, a pilot should be able to perform a safe autorotative landing. A 1995 accident involving a Bell 206L illustrates this situation (NTSB ID: CHI95LA093). Shortly after takeoff from Maryland Heights, MO, the helicopter lost engine power. The pilot was unable to perform a proper autorotation as the helicopter was operating in the hazardous region of the height-velocity curve. The helicopter sustained substantial damage after colliding with terrain. Fortunately, all five occupants walked away from this accident, uninjured.

Next, I discuss the different triggers for the improper autorotation state. The rules linking the improper autorotation state and different triggers are shown in Table 262 (Appendix

C). Triggers were available from accident reports for 56.6% of improper autorotation accidents. Table 50 shows the top five triggers from the accident reports.

Table 50: Top Triggers from the Database for Improper Autorotation (pre-2008)

| **Top Triggers for Improper Autorotation** | **Presence in Autorotation Accidents** |
|---|---|
| Not possible | 11.6% |
| Improper remedial action | 9.2% |
| Delayed action | 5.9% |
| Incorrect action | 3.5% |
| Improper inflight planning/decision-making | 3.5% |

In many accidents, circumstance prevent the pilot from performing a correct autorotation. The circumstances can include failure of vital components (e.g. collective pitch control lever) or phase of operation (e.g., hovering in the hazardous region of the Deadman's curve). The presence of the "not possible" trigger in 11.6% of autorotation accidents suggests that it was impossible to make an autorotative landing. For example, in April 1990, a Bell 47 was involved in a serious accident near Oakdale, MN (NTSB ID: MKC90LA088). In this accident, the rotor drive system failed (specifically, the clutch assembly), forcing the pilot to attempt an autorotation. During the attempted autorotation, it was impossible for the pilot to maintain rotor RPM, resulting in a collision with terrain.

Three of the top five trigger for improper autorotation point to some form of improper action by the pilot. *Improper remedial action* appears in 9.2% of improper autorotation accidents. Despite having a high presence in accidents, it provides little insight into the specific nature of the remedial action. The other two action-related triggers (i.e., delayed action and incorrect action) also have the same lack of specificity problem.

*Improper use of collective* appears sixth for improper autorotation. Correct use of collective pitch control is crucial to maintain rotor RPM during an autorotation (considering that engines are generally not operational during autorotations). As I noted earlier (in Table 49), many autorotations failed because the pilots did not maintain rotor RPM.

Next, I discuss the remaining 43.4% of improper autorotation accidents that did not have triggers in the accident reports. In these cases where it is not possible to identify the necessary triggers from the accident report, I infer triggers based on the rules linking the improper autorotation state and triggers.

Table 51: Inferred Triggers for Improper Autorotation (pre-2008)

| **Inferred Triggers for Improper Autorotation** | **Presence in Autorotation Accidents** |
|---|---|
| Improper use of collective (during simulated autorotation) | 10.3% |
| Improper use of collective and/or cyclic | 7.1% |

Table 51 shows the presence of the two inferred triggers in improper autorotation accidents. I inferred the Improper use of collective (during simulated autorotation) when the pilot failed to maintain rotor RPM after initiating a practice autorotation. Consider the example of a test-flight, where the company pilot was simulating an autorotation on a newly manufacture Bell L4 helicopter (NTSB ID: FTW91LA154). During the simulated autorotation, he failed to maintain rotor RPM (now in an improper autorotation state), and subsequently landed hard. In this accident, I infer that the pilot’s improper use of the collective led to the RPM decay.

The improper use of collective and/or cyclic trigger appears in 7.1% of accidents. As mentioned in Table 251 (Appendix B), I inferred this trigger only when the pilot failed to maintain rotor RPM or descent profile/rate after experiencing a loss of engine power.

### 5.3.3 Summary

In sections 5.3, I identified accidents that involved incorrect autorotations by using the modifiers in the NTSB accident database. Then, I applied the state-based approach to identify accidents with improper autorotations, and analyzed these accidents to identify the top reasons for poor autorotations. Table 52 summarizes the results from both analyses.

Table 52: Top Triggers that are inferred for the LOC State

<table>
<tr><th></th><th>Conventional Analysis</th><th>State-based Analysis</th><th>Remarks</th></tr>
<tr><td>Number of accidents identified</td><td>174</td><td>632</td><td>The larger set of accidents using the state-based approach can be attributed to the definition for this state, which involves a combination of subject codes, occurrences, and phase of flight code.<br><br>In the conventional analysis, improper autorotations can be found only using the modifiers.</td></tr>
<tr><td rowspan="2">Top modifier</td><td>Improper (4.9%)<br>(pre-2008)</td><td rowspan="2">-</td><td rowspan="2">The NTSB used the “performed” modifier frequently (48.2% of accidents that involved autorotations).<br><br>Among the modifiers that describe poor autorotations, the NTSB used “improper” most frequently.<br><br>After 2008, the NTSB represented autorotation as a phase of flight (and not a subject code). This code did not have any modifiers associated with it.</td></tr>
<tr><td>-</td></tr>
</table>

| | Conventional Analysis | State-based Analysis | Remarks |
|---|---|---|---|
| Top trigger from database | - | Not possible (11.6%) | In 11.6% of improper autorotation accidents, circumstances (e.g., component failures, hazardous height-velocity regime) made it impossible for the pilot to execute a correct autorotation. |
| Top inferred trigger | - | Improper use of collective (during simulated autorotation) (10.3%) | I inferred two triggers for the improper autorotation state. Improper use of collective during practice autorotations can trigger improper autorotations. |

Applying the state-based model helps us identify a larger set of accidents that involved improper autorotation accidents. As I mentioned earlier in this section, the NTSB used the "performed" modifier in almost half the accidents that involved autorotations. This modifier lends little information beyond the fact that pilots carried out autorotations. Using the NTSB modifiers for poor autorotations suggests that only a small proportion (13.6%) of accidents involved improper autorotations. Further, the change in the NTSB coding system (with the use of autorotation as a phase of flight) made it difficult to identify improper autorotations from a conventional analysis.

Results from the state-based analysis showed that not maintaining rotor RPM and improper flare were among the top reasons for improper autorotations. This information is not easily discerned using the conventional analysis because it (conventional analysis) does not take into account the key flight parameters (elements) that are part of the definition of an improper autorotation in the state-based model.

In 11.6% of improper autorotation accidents, circumstances (e.g., component failures, hazardous height-velocity regime) made it impossible for the pilot to execute a correct autorotation. Four of the top five triggers from the database involve some form of incorrect action or decision by the pilot. These triggers, while suggesting that the pilot “made a mistake”, do not provide additional information about the nature of the mistake.

## 5.4 Limitations of Data Source

### 5.4.1 NTSB Coding Manual

I developed the state-based accident model by using the codes provided in the NTSB coding manual. The state-based approach, while highlighting key differences compared to a conventional analysis, inherits some of the problems associated with the coding system.

The NTSB coding manual contains several non-informative/non-specific codes that translate to triggers such as *improper inflight planning/decision-making* or *incorrect action.* The broad nature of these triggers makes it difficult to link them to specific states—in other words, these triggers can potentially trigger multiple states in the same accident.

### 5.4.2 NTSB Dataset Analyzed

As mentioned earlier in this chapter, I applied the state-based accident model to 6200 helicopter accidents that occurred in the US in 1982–2015. The frequent appearance of certain non-informative/non-specific triggers limits our ability fully understand the causes for accidents. For example, the presence of triggers such as *inflight planning/decision-making* or *delayed action* in many fatal and non-fatal accidents do not provide any specific information that could be used to reduce/mitigate future accident risk.

# CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

US General Aviation (GA) has a diverse fleet composition and various mission types. GA aircraft account for almost 97% of all civil aviation aircraft in the US. GA operations involve more accidents (and fatalities) compared to commercial aviation (Part 121) operations. Recognizing the relatively high risk in GA operations, safety agencies (e.g., NTSB) and regulators (e.g., FAA) have called for improved safety levels.

One way to improve GA safety is to better understand accidents that have occurred. Several studies have used the NTSB's accident database to carry out retrospective accident analyses. These studies, generally, analyzed the accidents in the database using the NTSB accident coding manual—a guidebook that lends itself to event-based analyses of accidents. However, these studies, while providing some useful insights into accident causation, limit themselves by adhering to this event-based system.

This thesis has a developed an alternative approach to modeling aviation accidents by using a state-based approach. The method moves beyond an event-based approach by viewing aviation accidents as a set of hazardous states of a system (pilot and aircraft), and triggers that cause the system to move between hazardous states. As part of this approach, I used the NTSB's accident coding manual (that contains nearly 4000 different codes) to develop a "dictionary" of hazardous states, triggers, and information codes. Then, I created the "grammar", or a set of rules, that: (1) arranges hazardous states in accidents; and, (2) links triggers to different hazardous states. This approach helps: (1) provide a more correct count of the causes for accidents in the NTSB database; and, (2) checks for gaps or omissions in NTSB accident data, and fills-in some of these gaps using logic-based rules. These rules also help identify and count causes for accidents that were not discernable from previous analyses of historical accident data.

## 6.1 Summary

Chapter 1 introduced GA accidents and motivated the need to better understand GA accident causation.

Chapter 2 reviewed literature on aviation accident causation, with particular emphasis on studies that have looked at historical GA accidents. The second half of Chapter two reviewed the different accident modeling techniques—many of which have been used to understand the causes for aviation accidents.

The first part of Chapter 3 served as a “beginners guide to the NTSB database”. The second part of Chapter 3 analyzed over 6000 historical helicopter accidents to determine “common themes” or chains of occurrences. While this occurrence chain approach moved beyond a root cause analysis, it showed that helicopter accidents recorded in the database had short stories (i.e., occurrence chains with short chain lengths). This approach highlighted one of the shortcomings of the event-based approach to analyzing historical aviation accidents.

To move beyond an event-based analysis, Chapter 4 presented a state-based accident modeling approach. Chapter 4 developed a dictionary of hazardous states, triggers, and information codes. The latter part of Chapter 4 developed the grammar (or rules) that arranged hazardous states, and linked triggers to hazardous states.

Chapter 5 demonstrated the state-based accident model when applied to 6200 historical helicopter accidents. The first part of this chapter identified and compared the top hazardous states and triggers in fatal and non-fatal accidents. The second part of this chapter demonstrated that we can learn more about the causes for inflight loss of control accidents by using the state-based accident modeling approach. The third (and final) part of Chapter 5 applied the state-based approach and presented insights into the reasons for improper autorotation accidents.

## 6.2 Contributions

Despite many years of retrospective accident analysis, helicopter (and fixed wing GA) accidents continue to occur frequently, often resulting in fatalities and damage to property. The pursuit of trying to better understand the reasons behind these accidents raised the following fundamental question:

> *The NTSB database contains a wealth of data, but is not always logically complete and omissions—can we develop an approach that enables logical checking and potentially removes the omissions?*

To address this question, I broke it down into two research questions:

1. The current accident coding system limits our understanding of accident causation—can a different approach help?
2. Can we provide a more correct count and hence a more accurate ranking of the causes for accidents in the NTSB database?

To address the first question, I developed a state-based accident model. To build this model, I translated the codes in the NTSB coding manual, and created a dictionary of hazardous states, triggers, and information codes. After creating the vocabulary of states and triggers, I developed the grammar that: (1) sequences hazardous states in accidents; and (2) links triggers to hazardous states. This state-based accident model (complete with its dictionary and grammar) facilitates the analysis of historical accident data without needing to rely on/being restricted by the NTSB coding manual.

To address the second question, I applied the state-based accident modeling technique to better understand if we are correctly identifying and counting the causes for two of the top hazardous states in helicopter accidents: (1) infight loss of control (LOC); and (2) Improper autorotations. Results from the state-based analyses highlighted causes such as "clipping of object/terrain" that were not available from a conventional analysis of the database. Further, the state-based approach also inferred triggers for particular states, in accidents, when all the information was not in the coded accident reports. The state-based approach, while highlighting key differences compared to a conventional analysis, also points out issues that need to be addressed in future research. Examples of such issues include the frequent use of codes relating to poor decision-making or incorrect actions.

## 6.3 Recommendations for Future Work

The work in this research has unearthed several interesting research questions to consider in future work. Building on the work completed in this thesis, I present some of the ideas for future research in this chapter. It is my intent for each of these ideas to serve as stepping-stones for future research proposals.

### 6.3.1 Suggested Refinements of the State-based Approach

In the current version of the model, I used the grammar to infer triggers (that I defined) for specific states in an accident that did not have any triggers in the accident report. In future work, I propose creating more sophisticated rules that will allow us to infer triggers (for specific states) from the list of triggers that were translated from the NTSB coding manual.

For example, if an accident involves an *improper descent* state after the *disoriented/lack of awareness* state (and there is no code in the accident report that corresponds to a trigger for this state), then I could potentially infer the *lack of action* trigger that is coded in the coding manual.

Another suggested improvement is to develop a set of rules that could potentially help infer missing states in accident reports. For example, if an accident involves a *loss of engine power* followed by a *hard landing*, then, we can infer that accident might have involved an *improper autorotation* state.

### 6.3.2 Extending the Application of the State-based Approach

In this thesis, I showed that the state-based approach can help identify triggers for hazardous states that cannot be obtained from a conventional analysis of the accident database. I propose the following ideas as some of the logical next-steps for this research:

1. Applying the state-based approach to fixed-wing GA accident data. Fixed-wing aircraft account for nearly 80% of the GA fleet (and over 82% of the accidents recorded in the NTSB database in 1982–2015). I recommend using the state-based model to identify trigger events for high-risk hazardous states such as inflight loss of control (LOC) and controlled flight into terrain (CFIT). The nature of fixed-wing and helicopter operations is different; however, it might be worthwhile to explore similarities (if any) in the triggers for the top hazardous states.
2. The state-based approach can also be used to model accidents that occurred during towered/un-towered airport operations. I recommend using this approach to potentially capturing issues with communication between pilots and air traffic controllers (ATC) or between pilots, and estimating the frequency of trigger events

such as misinterpreted information, incorrect phraseology, or poor crew resource management (CRM) techniques.

3. Many accidents involve runway incursions, excursions, undershoot, and overruns. The state-based model can also capture hazardous states of the system when operating in different surface conditions.
4. The state-based model could also be used to model incidents. In this extension of the model, I would use incident data from the NTSB, FAA Accident and Incident Data System (AIDS), and NASA Aviation Safety Reporting System (ASRS). I would begin by mapping the different incident coding systems to the states and triggers that I defined in this thesis. Then, I would use these incident data to track different hazardous states (and trigger events) that ended in near misses, and compare them with accident data.

### 6.3.3 Bridging the Divide: Mapping the FDM World to Accident Data

Traditionally, researchers associate the terms Flight Operations Quality Analysis (FOQA) and Flight Data Monitoring (FDM) with the commercial aviation sector. Generally, aircraft used in commercial operations have on-board Flight Data Recorders (FDRs) that record several flight parameters at predefined frequencies. In the interest of safety and performance improvements, many commercial operators (in the US) voluntarily contribute their data to an Aviation Safety Analysis and Sharing (ASIAS) repository. Researchers have used these data to identify key parameters to be monitored during flight, and have also defined several FDM events—combinations of flight parameters that help capture unsafe situations during flight (e.g., High airspeed at low altitude).

More recently, there has been a concerted effort from regulators and members of the safety community to incorporate FDM analysis in the General Aviation (GA) sector. As I mentioned during my review of safety literature (Section 2.2), few GA aircraft are equipped with FDRs—making it challenging to collect flight data (and hence draw meaningful conclusion from analyses). However, I believe that careful analysis of historical GA accident data can provide us meaningful information about flight parameters that should be monitored. Here, I recommend the following:

1. A map between the codes used by the NTSB to record accident information and a predefined list of helicopter FDM events. This map could be used to potentially point us to high risk FDM events that have occurred frequently in past accidents.
2. Using Subject Matter Expert (SME) opinion to establish a link between these FDM events and hazardous states that frequently resulted in accidents (e.g., loss of control).

#### 6.3.4 Basic Accident Plots: Using Historical Data to Build Aviation Accident Archetypes

Most accident analysis techniques tend to focus on a single root cause or count the causes that appear most frequently in accidents. Through this thesis, I have demonstrated that the use of a state-based approach to model accidents potentially provides a richer understanding of accident causation. Building on the hazardous states and trigger events identified, I propose developing a set of GA accident archetypes that model the common stories (states and triggers) that often end in accidents.

These accident archetypes can also help capture organizational factors that contribute to accidents. While the term "Organizational influence" is more commonly used in accidents that involve the process industry (e.g., chemical plants, oil refineries), I believe that we can extend the use of the term to the realm of GA and helicopter operations. I intend to use the term organizational influence to better understand the safety culture of pilots, aircraft maintenance technicians (AMTs), and operators (e.g., law enforcement, search and rescue). In our attempts to reduce fatal accident rates, we (safety community) often focus on the causes at the sharp end of accidents, often relegating the underlying role of the pilot/organizational attitudes towards safety.

These archetypes, once developed, could be used to describe accidents. An example of a potential accident archetype is “Accidents that involved controlled flight into terrain or objects due to poor preflight planning”. In this example, I can explore the reasons for the poor preflight planning (e.g., management-induced time pressures, pure negligence). In addition, a time history of these archetypes might provide additional insight—if the number of accidents described by an archetype has increased, decreased, or remained the same, then we can track specific reasons for the change (or lack of it). Consider for example the above mentioned accident archetype; if the number of accidents per year has remained relatively unchanged, then I can explore reasons for the lack of change in the particular archetype (e.g., specific trigger events continue to occur despite changes in pilot training procedure).

### 6.3.5 Improving General Aviation Safety by Building an Accident Ontology

Greek philosophy defines “ontology” as the study of being or in existence. The domain of artificial intelligence defines it as a “specification of a conceptualization” (Gruber, 1993). Generally, ontologies are used to not just share data, but also establish semantics for using the data. Some researchers have developed ontologies that help with the aircraft design process, which involves mapping of data between various design tools. Using aircraft design ontology, Ast (2012) created a central data model that contained all the mapped information from the different tools. In addition, this central data model also helped check the plausibility of the maps between the different tools.

Some research has looked into the use of ontologies in the safety domain, particularly in the road traffic safety domain. Barrachina et al. (2012) developed a vehicular accident ontology network that combined automobile specifications, operator information, operating environment, historical accident data, and on-board sensor data to alert nearby vehicles and emergency personnel. Unfortunately, I have not come across any similar approaches in the aviation safety domain. Therefore, I suggest building an accident ontology by leveraging information from historical accident data, flight recorder data, pilot information, operating environment, and air.

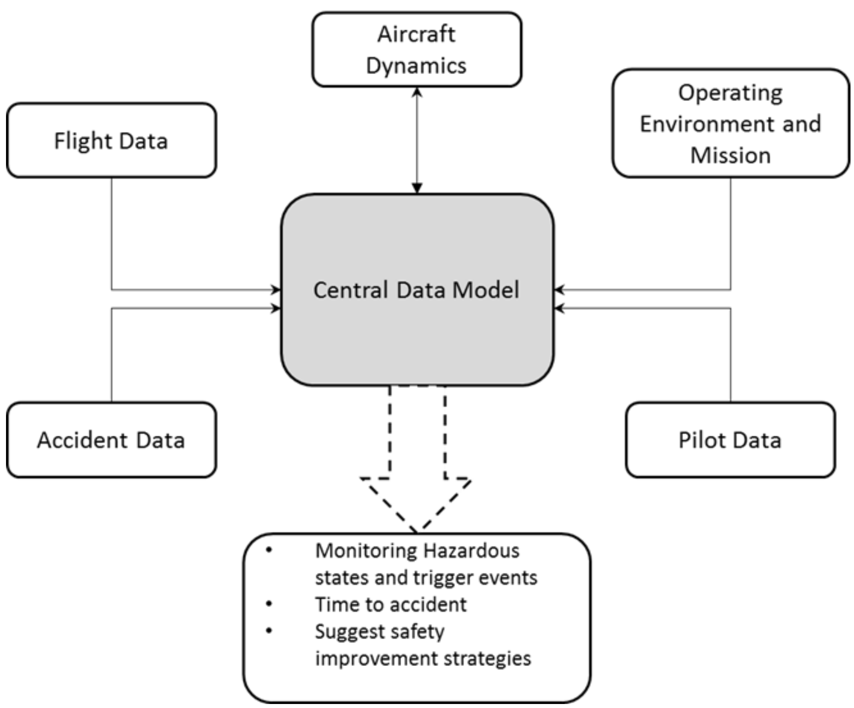


Figure 28: Framework for notional accident ontology. The central data model contains mapped information from the different data sources depicted in the framework.

Figure 28 presents an initial outline for this ontology. The central data model helps map (and exchange) data between the different data sources. Analysis of flight data could potentially reveal FDM events that were "flagged" during operation of the aircraft. Using this ontology structure, I can combine the flagged FDM events, flight crew information, and operating environment, compare it with historical accident data and potentially determine the risk of an accident associated with a flight. Furthermore, this ontology also allows for the analysis of flights using an aircraft dynamics model to recreate the flight and estimate the "hazard level" for the entire time interval of the flight.

### 6.3.6 The Pursuit of Completeness: Data Mining Applied to Accident Reports

As I mentioned earlier in this document, in addition to recording accidents in a coded system, the NTSB also provides brief summaries and detailed factual reports regarding accidents. These reports generally contain detailed witness and survivor accounts (in non-fatal accidents). To supplement the map between trigger events and hazardous states, I recommend using data mining approaches to identifying key information from accident reports.

Consider for example a 2012 accident involving a Schweizer 269C near Asheville, NC (NTSB ID: ERA12LA362). The accident coding system indicates that the skid shoe came loose due to improper maintenance resulting in a roll-over end state. However, closer examination of the accident report provides additional insight into the causes for this accident:

"*The pilot conducted the approach for landing at about 40 knots and touched down left of the runway centerline on both skids. As he lowered the collective, <u>the helicopter's right center skid shoe contacted a runway centerline light, shearing off the right skid and its</u>*

*support arms. The pilot raised the collective, picked the helicopter up to a hover, and turned towards the taxiway in order to land. Shortly after, the engine and rotor RPM began to drop, and the pilot opened the throttle and lowered the collective, setting the helicopter onto the left skid. The helicopter rolled over and came to rest on its right side, resulting in substantial damage to the main rotor blades. A post-accident examination by the pilot revealed that, during the right skid's impact with the centerline light, the front landing gear crossbeam was pushed aft, crimping the fuel supply line*".

While the coding system captures the fact that right skid sheared off, it does not indicate that the helicopter experienced low engine RPM due to crimping of the fuel line. The additional insight from the report helps complete the accident story by supplementing the information from the state-based model.

While there has been extensive work in the field of text mining and natural language processing (Wallace et al., 2003; Kloptchenko et al., 2004; Tseng et al., 2005), only a limited amount of work apply these techniques to accident/incident report analysis. Melby (2011) outlines how he (and the MITRE Company) developed the Aviation Information Retrieval and Extraction System (AIRES) to identify keywords and phrase from NTSB reports. Jeske and Liu (2007) used a naïve Bayes classifier to mine text data from FAA aviation safety report project. Bazargan et al. (2013) applied the AIRES software and Principal Component Analysis (PCA) to identify some of the key causes associated with fatal GA accidents in 1983–2009. The authors also suggest implementing machine learning techniques such as Self Organizing Maps (SOM) to improve the quality of text mining results. I recommend building on this body of text mining research to identify key words and phrases that can supplement the information obtained from the state-based approach.

# APPENDIX A. DEFINTIONS OF HAZARDOUS STATES

Table 53: Loss of Tail Rotor Effectiveness (LTE) State Definition

| **Loss of Tail Rotor Effectiveness (LTE)** | |
|---|---|
| Hazardous state where the helicopter tail rotor does not provide the requisite thrust to maintain directional control. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24805: Loss of tail rotor effectiveness | I identified these codes by searching the coding manual for the words “effectiveness” and “LTE”. |
| 24813: Tail rotor effectiveness AND (“not maintained”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 242: Loss of tail rotor effectiveness | I identified these codes by searching the coding manual for the words “effectiveness” and “LTE”. |

Table 54: Vortex Ring State (VRS) Definition

| **Vortex Ring State (VRS)** | |
|---|---|
| Hazardous state where a rapidly descending helicopter’s main rotor blades are engulfed by a doughnut-shaped vortex, resulting in a loss of lift. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24817: Vortex ring state | The circulation of air at the rotating blade tips is pushed downwards by aerodynamic forces resulting in a vortex, which reduces the lift and increases the drag on the blades. A rapidly descending helicopter experiences increased upward flow of air at the blade root and eventual blade root stall. Other contributing factors for VRS include increased collective pitch, high aircraft weight, low forward speed, and operating downwind.<br><br>I identified these codes by searching the coding manual for the phrases “vortex ring”, “loss of lift”, “settling with”, and the word “VRS”. |
| 24811: Settling with power | |
| **NTSB Codes (post-2008)** | **Notes** |
| 244: Settling with power/vortex ring state | Literature uses the terms loss of lift, vortex ring state, and settling with power interchangeably while describing this state. |
| 500: Loss of lift | |

| Vortex Ring State (VRS) | |
|---|---|
| Hazardous state where a rapidly descending helicopter's main rotor blades are engulfed by a doughnut-shaped vortex, resulting in a loss of lift. | |
| | I identified these codes by searching the coding manual for the phrases "vortex ring", "loss **of** lift", "settling with", and the word "VRS". |

Table 55: Improper RPM State Definition

| **Improper RPM State** | |
|---|---|
| Hazardous state where the main rotor RPM is either too low (or too high). | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 22308: Proper rotor RPM AND ("not maintained" OR "not possible" OR "not attained" OR "not available" OR "misjudged" OR "not followed" OR "delayed") | I identified these codes by searching the coding manual for the phrase "rotor RPM" and the word "RPM".<br><br>In one case, the NTSB did not use any modifier while describing the improper RPM state. |
| 24558: Rotor RPM AND ("not maintained" OR "misjudged" OR "low" OR "high" OR "inadequate" OR "reduced" OR "excessive" OR "exceed" OR "improper" OR "diminished" OR " not possible" OR "diminished" OR "not verified" OR "not identified" OR "not corrected" OR "not obtained/maintained" OR "not attained") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01062052XX: Performance/control parameters—Prop/rotor parameters AND ("not attained/maintained" OR "attain/maintain not possible" OR "capability exceeded") | Careful studying of several accident reports suggests that the NTSB use this code to indicate an improper rotor RPM situation. |

Table 56: Improper Altitude/Clearance State Definition

| **Improper Altitude/Clearance State** | |
|---|---|
| Hazardous state where the aircraft is operating too close to the ground, terrain, water, or object. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24518: Altitude AND ("inadequate" OR "misjudged" OR "low" OR "improper" OR "not maintained" OR "delayed" OR "below" OR "unavailable" ) | I identified these codes by searching the coding manual for derivatives of the words "altitude" and "clearance".<br><br>I also included "buzzing" and "low pass", which suggest that flights occurred at low altitudes.<br><br>In two cases, the NTSB used the modifier "inattentive" with this subject code. These cases suggest that the pilot was in a distracted state prior to the improper altitude/clearance state |
| 24519: Proper altitude AND ("not maintained" OR "not attained" OR "exceeded" OR "below" OR "misjudged") | |
| 24526: Clearance AND ("not maintained" OR "not attained" OR "exceeded" OR "inadequate" OR "not possible" OR "not obtained/not maintained" OR "improper" OR "misjudged") | |
| 24577: Altitude/clearance AND ("inadequate" OR "misjudged" OR "low" OR "improper" OR "not maintained" OR "not obtained/not maintained" OR "not verified") | |
| 24521: Buzzing AND ("intentional" OR "performed" OR "continued") | |
| 24541: Low pass AND ("performed" OR "intentional" OR "misjudged") | |
| **NTSB Codes (post-2008)** | **Notes** |

| Improper Altitude/Clearance State | |
|---|---|
| 01062012XX: Performance/control parameters-altitude AND (“not attained/maintained” OR “attain/maintain not possible” OR “incorrect use/operation OR “related operating info”) | I identified these codes by searching the coding manual for derivatives of the words “altitude” and “clearance”. |
| 290: Altitude deviation | |
| 220: Low altitude operations | |

Table 57: Rollover End State Definition

| Rollover State | |
|---|---|
| Hazardous state where when the helicopter skid/landing gear pivots about an object and exceeds the critical roll angle. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 380: Rollover | I identified these codes by searching the coding manual for derivatives of the word “rollover” and the phrase “dynamic rollover”.<br><br>In two cases, the NTSB modified the dynamic rollover state code with “initiated” and “performed”, respectively, to indicate the onset of a dynamic rollover. |
| 24801: Dynamic rollover | |
| **NTSB Codes (post-2008)** | **Notes** |
| 097: Rollover | I identified this code by searching the coding manual for derivatives of the word “rollover” and the phrase “dynamic rollover”. |

Table 58: Improper Climb State Definition

| Improper Climb State | |
|---|---|
| Hazardous state where the aircraft’s climb was incorrect/climb capability was exceeded/climb rate was incorrect. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17303: Aircraft performance-climb capability AND (“exceeded” OR “lack of” OR “deteriorated” OR “inadequate”) | I identified these codes by searching the coding manual for derivatives of the words “climb”.<br><br>In one case, the NTSB modified this subject code with “other” to indicate an improper climb state |
| 24527: Climb AND (“not maintained” OR “not attained” OR “improper” OR “inadequate” OR “not possible” OR “delayed” OR “excessive” OR “not performed” OR “initiated”) | |
| 24528: Proper climb rate AND (“not attained” OR “not maintained” OR “not possible” OR “not obtained”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01061010XX: Climb capability AND (“capability exceeded” OR “attain/maintain not possible” OR “not attained/maintained”) | I identified these codes by searching the coding manual for derivatives of the words “climb”. |
| 01062035XX: Climb rate AND (“capability exceeded” OR “not attained/maintained”) | |

Table 59: Improper Distance State Definition

| Improper Distance State | |
|---|---|
| Hazardous state where the distance from the runway/helipad/landing site is incorrect. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24523: Distance AND ("misjudged" OR "not obtained/maintained") | I identified these codes by searching the coding manual for the word "distance". |
| 24580: Distance/altitude AND ("misjudged" OR "not maintained" OR "low") | |
| 24581: Distance/speed AND ("misjudged") | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 60: Improper Heading State Definition

| Improper Heading State | |
|---|---|
| Hazardous state where the pilot failed to maintain heading/course. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01062047XX: Performance/control parameters-heading/course | I identified these codes by searching the coding manual for the words "course" and "heading". |
| 280: Course deviation | |

Table 61: Improper Airspeed State Definition

| Improper Airspeed State | |
|---|---|
| Hazardous state where the aircraft airspeed is either too low (or too high). | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24506: Airspeed AND ("not maintained" OR "excessive" OR "inadequate" OR "low" OR "misjudged" OR "not attained" OR "reduced" OR "not obtained/maintained" OR "misjudged" OR "below" OR "exceeded" OR "initiated" OR "high" OR "excessive") | I identified these codes by searching the coding manual for the word "airspeed".<br><br>Maintaining correct airspeed is critical to safe aircraft operations. Not maintaining airspeed can result in other hazardous states such as aerodynamic stall, VRS, or operating in the unsafe region of the Height-Velocity curve (also known as the Deadman's curve). |
| 24507: Airspeed-lift off speed AND ("not attained") | |
| 24509: Airspeed-minimum control speed with the critical engine inoperative AND ("not maintained") | |
| 24516: Airspeed-maximum operating limit speed AND ("exceeded") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01062010XX: Airspeed AND ("not attained/maintained" OR "capability exceeded") | I identified this code by searching the coding manual for the word "airspeed". |

Table 62: Improper Descent State Definition

| Improper Descent State | |
|---|---|
| Hazardous state where the aircraft's descent was incorrect/descent rate was incorrect. | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Improper Descent State | |
|---|---|
| 24524: Descent AND ("excessive" OR "not maintained" OR "exceeded", "improper" OR "inadvertent" OR "intentional" OR "misjudged" OR "premature" OR "not maintained/obtained" OR "not possible" OR "not corrected" OR "intentional" OR "premature") | I identified these codes by searching the coding manual for the word "descent". I did not include the "uncontrolled descent" phase of flight as I grouped it with the inflight loss of control state. |
| 24525: Proper descent rate AND ("excessive" OR "not maintained" OR "exceeded" OR "improper" OR "inadvertent" OR "intentional" OR "misjudged" OR "not maintained/obtained" OR "not possible" OR "not corrected") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01062037XX: Descent rate AND ("not attained/maintained" OR "incorrect use/operation" OR "capability exceeded" OR "attain/maintain not possible" OR "not specified" OR "related operating info") | I identified these codes by searching the coding manual for the word "descent". |
| 01062040XX: Descent/approach/glide path AND ("not attained/maintained" OR "incorrect use/operation" OR "capability exceeded" OR "attain/maintain not possible" OR "not specified") | |

I classified the poor weather state into:

1. Intentional/Inadvertent flight through poor weather state: This state appears in accidents where pilots knowingly or inadvertently flew through poor weather conditions.

Table 63: Intentional/Inadvertent flight through poor weather state Definition

| **Intentional/Inadvertent flight through poor weather state** | |
|---|---|
| Hazardous state where the pilot intentionally or inadvertently flew into poor weather conditions. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 240: Inflight encounter with weather | I identified these codes by searching the coding manual for the phrase that contained the words "VFR" and IMC". I supplemented this search with the careful study of accident reports to identify the phrase "adverse weather" that captures the other two codes.<br><br>In many instances, these subject codes are accompanied by "20000: Weather condition", which provides additional information about the nature of poor weather (e.g., clouds, whiteout, icing) that the pilot intentionally/inadvertently flew into. |
| 24015: VFR flight into IMC AND ("continued" OR "intentional" OR "inadvertent" OR "attempted" OR "initiated" OR "encountered" OR "improper" OR "misjudged") | |
| 24036: Flight into adverse weather AND ("continued" OR "intentional" OR "inadvertent" OR "attempted" OR "initiated" OR "performed" OR "selected") | |
| 24023: Flight into known adverse weather AND ("continued" OR "intentional" OR "inadvertent" OR "attempted" OR "initiated") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 401: VFR encounter with IMC | I identified this codes by searching the coding manual |
| 210: Icing encounter | |

| Intentional/Inadvertent flight through poor weather state | |
|---|---|
| | for the phrase that contained the words "VFR" and IMC". I also included the occurrence code that corresponded to icing (coded as a modifier in the pre-2008 system).<br>The search for "adverse weather" returned no results. |

2. Prevailing/Existing weather and light state: Not all poor weather accidents need necessarily involve intentional/inadvertent flight through poor weather. While flight in the prevailing weather (or light) state (e.g., high density altitude, tailwind, or glare) can be considered less hazardous (than, say, VFR flight into IMC), they may still play a role in the accident.

Table 64: Prevailing/Existing weather state Definition

| Prevailing/Existing weather and light state | |
|---|---|
| Hazardous weather state that existed during the flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 20000: Weather condition<br>20100: Light condition | I identified these codes by searching the coding manual for the phrase that contained the words "weather" and "light". I excluded the codes corresponding to inadvertent/intentional flight into adverse weather.<br>I also excluded the codes relating to aircraft lighting (e.g., panel lights). |
| **NTSB Codes (post-2008)** | **Notes** |
| 0303**YYYY**XX: Environmental issues-conditions/weather/phenomena | I identified these codes by searching the coding manual for the phrase that contained the words "weather" and "light". I excluded the codes corresponding to inadvertent/intentional flight into adverse weather.<br>I also excluded the codes relating to aircraft lighting (e.g., panel lights).<br><br>Here, **YYYY** represents that different weather and light conditions that are recorded under the Environmental |

| Prevailing/Existing weather and light state | |
|---|---|
| | issues-conditions/weather/phenomena hierarchy. **YYYY** ranges from “0000: general” to “6030: Light condition-glare” |

Table 65: Wake Turbulence state Definition

| Wake turbulence State | |
|---|---|
| Hazardous state where the aircraft flew through the wake vortices of another aircraft. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24715: Wake turbulence AND (“encountered” OR “inadvertent”) | I identified these codes by searching the coding manual for the phrases “wake turbulence” and “vortex turbulence”. |
| 410: Vortex turbulence encountered | |
| **NTSB Codes (post-2008)** | **Notes** |
| 361: Aircraft wake turbulence | I identified this code by searching the coding manual for the phrases “wake turbulence” and “vortex turbulence”. |

Table 66: Improper Turn/Bank state Definition

| Improper Turn/Bank State | |
|---|---|
| Hazardous state where the aircraft exceeds its banking/roll performance during flight | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17305: Aircraft performance-turn capability AND (“total loss” OR “exceeded”) | I identified these codes by searching the coding manual words “turn”, “roll”, and “bank”. |
| 17306: Aircraft performance-rolling maneuvers AND (“dynamic imbalance” OR “extraneous”) | |
| 24804: Hovering turn AND (“low” OR “abrupt” OR “uncontrolled”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 67: Runway Overshoot State Definition

| Runway Overshoot State | |
|---|---|
| Hazardous state where the aircraft departed the runway surface during takeoff or landing. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 390: Overrun | I identified this code by searching the coding manual for the word “overrun” and “excursion”. The terms overrun and excursion are used interchangeably. |
| **NTSB Codes (post-2008)** | **Notes** |
| 370: Landing area overshoot | I identified this code by searching the coding manual for the word “overrun” and “excursion”. The terms overrun |
| 300: Runway excursion | |

| Runway Overshoot State | |
|---|---|
| | and excursion are used interchangeably. |

Table 68: Loss of Engine Power State Definition

| Loss of Engine Power State | |
|---|---|
| Hazardous state where an aircraft's engine is not operational. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 350: Loss of engine power | I identified these codes by searching the coding manual for the phrases "loss of engine" and "powerplant". I do not include the codes relating to powerplant control, powerplant fire systems and extinguishers<br><br>Note that despite grouping mechanical and non-mechanical losses of engine power, I can count the instances where each of the codes appeared in accidents. |
| 351: Loss of engine power (total)-mechanical failure/malfunction | |
| 352: Loss of engine power (partial)-mechanical failure/malfunction | |
| 353: Loss of engine power (total)—non-mechanical | |
| 354: Loss of engine power (partial)—non-mechanical | |
| 16902: Powerplant AND ("failure, total" OR "seized" OR "fire" OR "overspeed" OR "output low") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 340: Powerplant system/component malfunction/failure | I identified these codes by searching the coding manual for the phrases "loss of engine" and "powerplant".<br><br>Note that despite grouping mechanical and non-mechanical losses of engine power, I can count the instances where each of the codes appeared in accidents. |
| 341: Loss of engine power (total) | |
| 342: Loss of engine power (partial) | |

Table 69: System Failure State Definition

| System Failure State | |
|---|---|
| Hazardous state where an aircraft's system(s)/component(s) have failed/malfunctioned. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 130: Airframe/component/system failure/malfunction | I identified these codes by searching the coding manual for the words "malfunction", "failure/malfunction", and "failure". I do not include powerplant failures in this category.<br><br>Note that despite grouping codes that convey the same meaning (i.e., system failure state), I can count the |
| 131: Propeller failure/malfunction | |
| 132 Rotor failure/malfunction | |

| System Failure State | |
|---|---|
| Hazardous state where an aircraft's system(s)/component(s) have failed/malfunctioned. | |
| | instances where each of the codes appeared in accidents. |
| **NTSB Codes (post-2008)** | **Notes** |
| 330: System/component malfunction/failure (non-powerplant) | I identified these codes by searching the coding manual for the words "malfunction", "failure/malfunction", and "failure". I do not include powerplant failures in this category.<br><br>Note that despite grouping codes that convey the same meaning (i.e., system failure state), I can count the instances where each of the codes appeared in accidents. |
| 331: Pressure/environmental system malfunction/failure | |
| 332: Electrical system malfunction/failure | |
| 333: Flight control system malfunction/failure | |
| 334: Flight instrument malfunction/failure | |
| 335: Navigation system malfunction/failure | |
| 336: Communication system malfunction/failure | |
| 337: Aircraft structural failure | |

Table 70: Preflight Mechanical Issue State Definition

| Preflight Mechanical Issue State | |
|---|---|
| Hazardous state where the flight begins with a pre-existing mechanical problem with the aircraft. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24006: Aircraft weight and balance AND ("exceeded" OR "disregarded" OR "high" OR "improper" OR "misjudged" OR "excessive" OR "selected" OR "attempted" OR "not verified" OR "inaccurate" OR "not corrected" OR "not calculated") | I identified these codes by searching in the coding manual for NTSB codes that suggested mechanical issues before the flight began (note that I consider improper weight a mechanical issue). I also studied several accident reports and noticed that the NTSB used these codes while referring to preflight mechanical problems.<br><br>In addition to these two subject codes, I define the preflight mechanical issue state using following triggers: improper maintenance (24100–24124, 24703), improper design by the manufacturer/builder (82000–82200), improper use of material (84000–84200), insufficiently defined procedure for maintenance personnel (80000–80400), insufficient/unclear information provided to maintenance personnel (35000–35310), and insufficient aircraft |
| 24007: Operation with known deficiencies AND ("continued" OR "attempted" OR "intentional" OR "performed" OR "attempted" OR "improper use of" OR "poor" OR "selected" OR "disregarded") | |

| Preflight Mechanical Issue State | |
|---|---|
| Hazardous state where the flight begins with a pre-existing mechanical problem with the aircraft. | |
| | certification/standards (91000, 91200, 91400, 92000, and 92400). |
| **NTSB Codes (post-2008)** | **Notes** |
| 01061040XX: CG/weight distribution AND ("capability exceeded") | I identified these codes by searching in the coding manual for NTSB codes that suggested mechanical issues before the flight began (note that I consider improper weight a mechanical issue). I also studied several accident reports and noticed that the NTSB used these codes while referring to preflight mechanical problems |
| 01061035XX: Maximum weight AND ("capability exceeded OR "not specified" OR "incorrect use/operation") | |

Table 71: Preflight Pilot Hazardous State Definition

| Preflight Pilot Hazardous State | |
|---|---|
| Hazardous pilot state that does not involved psychological conditions, physical impairment, confidence, fatigue, or qualification/experience related states. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| • I identified this state using the triggers shown in the notes column. This state does not correspond to any of the other pilot-related hazardous states. | I identified this code by using the triggers:<br>• 35200: Information unavailable.<br>• 35100: Information insufficient.<br>• I excluded the non-pilot related personnel codes. |
| **NTSB Codes (post-2008)** | **Notes** |
| • I identified this state using the triggers shown in the notes column. This state does not correspond to any of the other pilot-related hazardous states. | • 04024010XX: Management—safety culture<br>• 04024015XX: Management—standard operating practices<br>• 04031000XX: Support/oversight/monitoring—training<br>• 04031010XX: Support/oversight/monitoring—initial training<br>• 04031020XX: Support/oversight/monitoring—upgrade training<br>• 04031030XX: Support/oversight/monitoring—emergency procedure training<br>• 04032000XX: Support/oversight/monitoring—general |

| Preflight Pilot Hazardous State | |
|---|---|
| | • 04032015XX: Support/oversight/monitoring—oversight of operation<br>• 04035010XX: Support/oversight/monitoring—Availability of safety programs<br>• 04035015XX: Support/oversight/monitoring—Adequacy of safety programs<br>• 04035020XX: Support/oversight/monitoring—Adherence to safety programs<br>• 030: Preflight or dispatch event<br>• I only included modifiers corresponding to the "operator" |

Table 72: Aircraft Stall/Spin State Definition

| **Aircraft Stall/Spin State** | |
|---|---|
| Hazardous state where the lifting surfaces of an aircraft (i.e., wings or rotor blades) exceed a critical angle of attack they experience a loss of lift, and enter a stalled state | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24551: Stall AND ("inadvertent" OR "uncontrolled" OR "not corrected") | I identified these codes by searching the coding manual for the words "stall", "stall/spin", "spiral", and "rotation". I exclude codes relating to engine/compressor stalls.<br><br>When the lifting surfaces of an aircraft (i.e., wings or rotor blades) exceed a critical angle of attack they experience a loss of lift, and enter a stalled state. Any yawing motion in this stalled state can induce a spin. The NTSB uses the "uncontrolled" modifier to suggest that loss of control followed the stall/spin state |
| 24552: Stall/spin AND ("uncontrolled" OR "inadvertent") | |
| 24550: Spiral AND ("not possible" OR "uncontrolled" OR "inadvertent") | |
| 24548: Rotation AND ("uncontrolled") | |
| 24809: Retreating blade stall AND ("encountered") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 241: Aerodynamic stall/spin | I identified these codes by searching the coding manual for the words "stall", "stall/spin", "spiral", and "rotation". I exclude codes relating to engine/compressor stalls. |
| 243: Retreating blade stall | |

Table 73: Disoriented/Lacking Awareness State Definition

| **Disoriented/Lacking Awareness State** | |
|---|---|
| Hazardous state where the pilot is lost, disoriented, unable to maintain visual reference/perception. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 33400: Spatial disorientation | I identified these codes by searching the coding manual for derivatives of the word “disorient” and “aware”, and the words “lost”, “perception”, and “illusion”. |
| 24014: Became lost/disoriented | |
| 31210: Visual/aural perception | |
| 31211: Visual illusion | |
| 33500: Visual/aural detection | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02022000XX: Perception/orientation/illusion—general | I identified these codes by searching the coding manual for derivatives of the word “disorient” and “aware”, and the words “lost”, “perception”, and “illusion”. |
| 02022015XX: Perception/orientation/illusion—Visual illusion/disorientation | |
| 02022025XX: Perception/orientation/illusion—spatial disorientation | |
| 02022035XX: Perception/orientation/illusion—Situational awareness | |
| 02022040XX: Perception/orientation/illusion—Perception | |

Table 74: Physically Impaired/Incapacitated State Definition

| **Physically Impaired/Incapacitated State** | |
|---|---|
| Hazardous state where the pilot was impaired or incapacitated. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 33200: Incapacitation (general) | I identified these codes by searching the coding manual for derivatives of the word “impair” and “incapacitate”. Note that I do not include the code “33141: Use of drugs”—I term this code a trigger. |
| 33212: Incapacitation (cardiovascular) | |
| 33214: Incapacitation (carbon monoxide) | |
| 33218: Incapacitation (motion sickness) | |
| 33221: Incapacitation (other organic problem) | |
| 33100: Physical impairment | |
| 33115: Physical impairment (other toxic) | |
| 33116: Physical impairment (hypoglycemia/diet) | |
| 33119: Physical impairment (stroke) | |
| 33120: Physical impairment (visual deficiency) | |
| 33121: Physical impairment (other organic problem) | |
| 33130: Impairment (alcohol) | |
| 33140: Impairment (drugs) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02012000XX: Impairment/incapacitation (general) | I identified these codes by searching the coding manual for derivatives of the word “impair” and “incapacitate”. |
| 02012010XX: Impairment/incapacitation—Illness/injury | |
| 02012020XX: Impairment/incapacitation—Illicit drug | |
| 02012025XX: Impairment/incapacitation—Prescription medication | |
| 02012030XX: Impairment/incapacitation—OTC medication | |
| 02012045XX: Impairment/incapacitation—Neurological | |
| 02012050XX: Impairment/incapacitation—Cardiovascular | |
| 02011030XX: Impairment/incapacitation—Physical characteristic-Physical limitation | |
| 02011510XX: Impairment/incapacitation—Sensory ability/limitation - Visual function | |

Table 75: Lack of Visual Lookout/Distracted State Definition

| **Lack of Visual Lookout/Distracted State** | |
|---|---|
| Hazardous state where the pilot failed to maintain visual lookout for terrain/other aircraft or was distracted. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24610: Monitoring AND (“inadequate” OR “inattentive” OR “not maintained”) | I identified these codes by searching the coding manual for derivatives of the word “monitor”, “divert”, and “distract”. I supplemented this search by looking for instances where pilot’s failed to maintain “lookout” or “separation”. |
| 31110: Diverted attention | |
| 31120: Inattentive | |
| 24021: Visual lookout AND (“inadequate” OR “not maintained” OR “not possible” OR “restricted” OR “reduced” OR “diminished” OR “poor” OR “inaccurate” OR “improper” OR “not attained” OR “restricted” OR “inattentive” OR “not performed” “attempted” OR “not received” OR “inadvertent” OR “disregarded” OR “misjudged” OR “not understood”) | |
| 24618: Visual separation AND (“not maintained” OR “inadequate” OR “inattentive”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02021500XX: Attention/monitoring (general) | I identified these codes by searching the coding manual for derivatives of the word “monitor”, “divert”, and “distract”. |
| 02021525XX: Monitoring equipment/instruments | |
| 02021530XX: Monitoring other person | |
| 02021535XX: Monitoring other aircraft | |
| 02021540XX: Monitoring environment | |

Table 76: Overconfident/Lack of Confidence State Definition

| **Overconfident/Lack of Confidence State** | |
|---|---|
| Hazardous state where the pilot demonstrated lack of/overconfidence in his/her/aircraft’s ability. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 31140: Complacency | I identified these codes by searching the coding manual for derivatives of the word “confidence” and “complacent”. I included ostentatious display as it suggests a hazardous pilot attitude. |
| 31150: Under-confidence in personal ability | |
| 31170: Overconfidence in aircraft’s ability | |
| 31260: Ostentatious display | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02021010XX: Personality/attitude self-confidence | I identified these codes by searching the coding manual for derivatives of the word “confidence” and “complacent”. |
| 02021015XX: Confidence/reliance on equipment | |
| 02021020XX: Complacency | |

Table 77: Insufficient Qualification/Training State Definition

| **Insufficient Qualification/Training State** | |
|---|---|
| Hazardous state where the pilot did not meet the qualification/training requirements to perform the flight | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 34000: Qualification | I identified these codes by searching the coding manual for derivatives of the word |
| 34001: Lack of certification | |
| 34100: Improper training | |

| Insufficient Qualification/Training State | |
|---|---|
| 34110: Improper initial training | "train", "knowledge", and "experience".<br><br>Note that I do not include codes relating to the lack of training procedure provided by the company, management, or regulator. |
| 34200: Inadequate training | |
| 34210: Inadequate initial training | |
| 34220: Inadequate recurrent training | |
| 34230: Inadequate transition/upgrade training | |
| 34240: Inadequate training (emergency procedure(s)) | |
| 34300: Lack of experience | |
| 34310: Lack of familiarity with aircraft | |
| 34320: Lack of familiarity with geographic area | |
| 34330: Lack of total experience | |
| 34331: Total (experience) | |
| 34332: Lack of total experience in kind of aircraft | |
| 34333: Lack of total experience in type of aircraft | |
| 34334: Lack of total instrument time | |
| 34335: Lack of total experience in type operation | |
| 34340: Lack of recent experience | |
| 34341: Lack of recent total experience | |
| 34342: Lack of recent experience in kind of aircraft | |
| 34343: Lack of recent experience in type of aircraft | |
| 34344: Lack of recent instrument time | |
| 34345: Lack of recent experience in type operation | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02030000XX: Experience/knowledge (general) | I identified these codes by searching the coding manual for derivatives of the word "train", "knowledge", and "experience".<br><br>Note that I do not include codes relating to the lack of training procedure provided by the company, management, or regulator. |
| 02031000XX: Experience/qualifications (general) | |
| 02031010XX: Qualification/certification | |
| 02031015XX: Total experience | |
| 02031020XX: Total experience in position | |
| 02031025XX: Total experience w/ equipment | |
| 02031030XX: Total instrument experience | |
| 02031035XX: Recent experience | |
| 02031045XX: Recent experience w/ equipment | |
| 02031515XX: Initial instruct/training | |
| 02031530XX: Training with equipment | |
| 02032000XX: Knowledge (general) | |
| 02032010XX: Knowledge of procedures | |
| 02032015XX: Knowledge of equipment | |
| 02032025XX: Knowledge of regulatory requirements | |
| 02032030XX: Knowledge of geographic area | |
| 02032035XX: Aeronautical knowledge | |

Table 78: Fatigued/Overworked State Definition

| Fatigued/Overworked State | |
|---|---|
| Hazardous state where the pilot was fatigued/overworked. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 33600: Fatigue | I identified these codes by searching the coding manual for the word "fatigue", "overworked", and "workload". |
| 33601: Fatigue (conditions conducive to pilot fatigue) | |
| 33610: Fatigue (chronic) | |
| 33620: Fatigue (lack of sleep) | |
| 33630: Fatigue (flight schedule) | |
| 33650: Fatigue (flight and ground schedule) | |
| 33660: Fatigue (circadian rhythm) | |

| Fatigued/Overworked State | |
|---|---|
| **NTSB Codes (post-2008)** | **Notes** |
| 02013500XX: Alertness/Fatigue (general) | I identified these codes by searching the coding manual for the word "fatigue", "overworked", and "workload". |
| 02013510XX: Lack of sleep | |
| 02013520XX: Fatigue due to work schedule | |
| 02064000XX: Workload management (general) | |
| 02064010XX: Task scheduling | |
| 02064015XX: Task load shedding | |
| 02064020XX: Task allocation | |
| 02064025XX: Task overload | |

Table 79: Anxiety/Under Pressure State Definition

| Anxiety/Under Pressure State | |
|---|---|
| Hazardous state where the pilot was anxious or under pressure while operating the aircraft | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 31200: Pressure | I identified these codes by searching the coding manual for derivatives of the words "pressure" and "anxiety", and the word "panic". |
| 31201: Self-induced pressure | |
| 31203: Pressure induced by others | |
| 31204: Pressure induced by conditions/events | |
| 31180: Anxiety/apprehension | |
| 31190: Panic | |
| **NTSB Codes (post-2008)** | **Notes** |
| 03042000XX: Pressure/demands (general) | I identified these codes by searching the coding manual for derivatives of the words "pressure" and "anxiety", and the word "panic". |
| 03042035XX: Personal pressure | |
| 03042040XX: Other pressure/demand | |
| 02022515XX: Anxiety/panic | |

Table 80: Poor Psychological State Definition

| Poor Psychological State | |
|---|---|
| Hazardous state where the pilot was in poor state of mind prior to the flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 31000: Psychological condition | I defined this state to capture the codes corresponding to general psychological conditions that did not have accompanying modifiers. |
| 31280: Other psychological condition | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02020000XX: Psychological (general) | I defined this state to capture the codes corresponding to general psychological conditions that did not have accompanying modifiers. |

Table 81: Exceeding Slope Limitation State Definition

| Exceeding Slope Limitation State | |
|---|---|
| Hazardous state where the pilot operated the aircraft beyond its design capability in inclined/sloped terrain. | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Exceeding Slope Limitation State | |
|---|---|
| 24576: Slope capability AND ("exceeded") | I identified these codes by searching the coding manual for the word "slope".<br><br>These codes describe the hazardous state where the pilot operated the aircraft beyond its capability on sloped terrain. Not recognizing (and correcting) this hazardous state can result in a roll over. |
| 24812: Slope limitations AND ("exceeded") | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 82: Improper Aircraft Weight and Balance State Definition

| Improper Aircraft Weight and Balance State | |
|---|---|
| Hazardous state where the aircraft's balance is affected due to improper loading or shifting of the center of gravity. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24006: Aircraft weight and balance AND ("exceeded" OR "disregarded" OR "high" OR "improper" OR "misjudged" OR "excessive" OR "selected" OR "attempted" OR "not verified" OR "inaccurate" OR "not corrected" OR "not calculated") | I identified this code by searching the coding manual for the words "weight" and "balance". |
| **NTSB Codes (post-2008)** | **Notes** |
| 01061040XX: CG/weight distribution AND ("capability exceeded") | I identified this code by searching the coding manual for the words "weight" and "balance". |
| 01061035XX: Maximum weight AND ("capability exceeded OR "not specified" OR "incorrect use/operation") | |

Table 83: Wheels-up Landing State Definition

| Wheels-up Landing State | |
|---|---|
| Hazardous state where the pilot performs a landing without extending the landing gear. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 232: Wheels-up landing | I identified these codes by searching the coding manual for the phrase "wheels-up". |
| 24556: Wheels-up landing | |
| **NTSB Codes (post-2008)** | **Notes** |
| 095: Landing gear not configured | In the post-2008 system, the NTSB used this code to indicate situations where there were wheels-down landings in water and wheels-up landings. |

Table 84: Runway Incursion State Definition

| Runway Incursion State | |
|---|---|
| Hazardous state where the aircraft did not transition correctly from forward flight to landing. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |

| Runway Incursion State | |
|---|---|
| 310: Runway incursion by animal | I identified this code by searching the coding manual for the word “incursion”. |
| 320: Runway incursion by vehicle/person/aircraft | |

Table 85: Low Fuel State Definition

| **Low Fuel State** | |
|---|---|
| Hazardous state where the aircraft was operating with low fuel level. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17001: Fuel AND (“low level”) | I identified these codes by searching the coding manual for the words “fuel”. I also included those instances that had the modifier “low level”. I did not include codes corresponding fuel systems. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071010XX: Fuel AND (“fluid level”) | I identified these codes by searching the coding manual for the words “fuel”. I also included those instances that had the modifier “fluid level”. I did not include codes corresponding fuel systems. |

Table 86: Low Oil State Definition

| **Low Oil State** | |
|---|---|
| Hazardous state where the aircraft was operating with low oil level. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17002: Oil AND (“low level”) | I identified these codes by searching the coding manual for the words “Oil”. I also included those instances that had the modifier “low level”. I did not include codes corresponding oil systems. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071020XX: Oil AND (“fluid level”) | I identified these codes by searching the coding manual for the words “Oil”. I also included those instances that had the modifier “fluid level”. I did not include codes corresponding oil systems. |

Table 87: Low Hydraulic Fluid State Definition

| **Low Hydraulic Fluid State** | |
|---|---|
| Hazardous state where the aircraft was operating with low hydraulic fluid level. | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Low Hydraulic Fluid State | |
| --- | --- |
| 17003: Hydraulic AND (“low level”) | I identified these codes by searching the coding manual for the words “hydraulic”. I also included those instances that had the modifier “low level”. I did not include codes corresponding hydraulic reservoir capacity and systems. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071015XX: Hydraulic fluid AND (“fluid level”) | I identified these codes by searching the coding manual for the words “hydraulic”. I also included those instances that had the modifier “fluid level”. I did not include codes corresponding hydraulic reservoir capacity and systems. |

Table 88: Improper Flare State Definition

| Improper Flare State | |
| --- | --- |
| Hazardous state where the pilot executed an improper flare prior to landing. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24535: Flare AND (“misjudged” OR “not possible” OR “not attained”, “delayed” OR “inadequate” OR “low” OR “high” OR “premature” OR “reduced” OR “abrupt” OR “improper” OR “not possible” OR “excessive” OR “not performed” OR “abrupt” OR “inaccurate” OR “not successful” ) | In one case, the NTSB used the modifier “inattentive” with this subject code. This cases suggests that the pilot was in a distracted state prior to the improper flare/level-off state. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01062041XX: Landing flare AND (“not attained/maintained” OR “incorrect use/operation” OR “not specified”) | |

Table 89: Improper Supervision State Definition

| Improper Supervision State | |
| --- | --- |
| Hazardous state where the instructor failed to correctly supervise the student pilot. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24627: Supervision | I identified this state by searching the coding manual for derivatives of the word “supervise”. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 90: Hazardous Height-Velocity Regime State Definition

| Hazardous Height-Velocity Regime State | |
| --- | --- |
| Hazardous state where the aircraft is operating in the unsafe region of the “Deadman’s curve”. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24803: Height/velocity curve | In some accidents that involved loss of engine power or |

| Hazardous Height-Velocity Regime State | |
|---|---|
| | improper autorotation, the NTSB used this code to indicate that at the aircraft was operating in a hazardous region of the Deadman's curve. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 91: On-ground Loss of Control State Definition

| On-ground Loss of Control State | |
|---|---|
| Hazardous state where the pilot failed to maintain control of the aircraft on the ground. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 260: On-ground loss of control | I identified these codes by searching the coding manual for the phrase "loss of control" and "ground" |
| **NTSB Codes (post-2008)** | **Notes** |
| 230: Loss of control on ground | I identified these codes by searching the coding manual for the phrase "loss of control" and "ground" |

Table 92: On-ground Poor Weather Definition

| On-ground Poor Weather State | |
|---|---|
| Hazardous state where the pilot intentionally/inadvertently flew through poor weather on the ground. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 330: On-ground encounter with weather | I identified these codes by searching the coding manual for the phrase "weather" and "ground" |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 93: Improper Run-on Landing State Definition

| Improper Run-on Landing State | |
|---|---|
| Hazardous state where the aircraft did not transition correctly from forward flight to landing. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24559: Run-on landing AND ("improper" AND "inadvertent" OR "misjudged" OR "inadequate" OR "not performed") | I identified this code by searching the coding manual for the phrase "run-on". |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 94: Improper Vertical Takeoff State Definition

| Improper Vertical Takeoff State | |
|---|---|
| Hazardous state where the pilot did not perform a correct vertical takeoff. | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Improper Vertical Takeoff State | |
|---|---|
| 24559: Vertical takeoff AND ("improper" AND "uncontrolled" OR "not possible" OR "restricted" ) | I identified this code by searching the coding manual for the phrase "vertical takeoff". |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 95: Improper Go-around State Definition

| **Improper Go-around State** | |
|---|---|
| Hazardous state where the pilot did not perform a correct go-around. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24536: Go-around AND ("inadvertent" OR "improper" OR "not possible") | I identified this code by searching the coding manual for the phrase "go-around". |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 96: Exceeding Design Stress Limits State Definition

| **Exceeding Design Stress Limits State** | |
|---|---|
| Hazardous state where aerodynamic loads on the aircraft exceed the design stress limits. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24538: Design stress limits of aircraft AND ("exceeded") | I identified this code by searching the coding manual for the words "design" and "stress".<br>I exclude codes relating to improper aircraft design and pilot stress/anxiety. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 97: Improper Translational Lift State Definition

| **Improper Translational Lift State** | |
|---|---|
| Hazardous state where the aircraft did not transition correctly from hover to forward flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24815: Translational lift AND ("not attained/maintained" OR "not maintained" OR "not attained" OR "not obtained") | I identified this code by searching the coding manual for the phrase "translational lift". |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 98: Improper Precautionary Landing State Definition

| **Improper Precautionary Landing State** | |
|---|---|
| Hazardous state where the pilot did not execute a proper precautionary landing. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24546: Precautionary landing AND ("not performed" OR "misjudged") | The NTSB used this code to indicate that the pilot had the option of choosing an |

| Improper Precautionary Landing State | |
|---|---|
| | appropriate landing area (unlike during a forced landing). |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 99: Mental Overload State Definition

| **Mental Overload State** | |
|---|---|
| Hazardous state where the pilot's abilities are limited as he/she is overwhelmed mentally. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 31220: Mental performance overload | I identified this code by searching the coding manual for the phrase "mental overload". |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 100: Unattended Aircraft State Definition

| **Unattended Aircraft State** | |
|---|---|
| Hazardous state where the aircraft is left unattended with the engines running. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24005: Aircraft unattended/engine(s) running | I identified this code by searching the coding manual for the word "unattended". This state is a preflight hazardous state as it involves leaving the controls of the aircraft unattended when on the ground (with engines running), before flight. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 101: Hazardous Powerplant Operation State Definition

| **Hazardous Powerplant Operation State** | |
|---|---|
| Hazardous state where the aircraft powerplant parameters are in excess of the specified operational limits. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01062050XX: Performance/control parameters—powerplant parameters | The NTSB introduced this code in the post-2008 system to indicate that the powerplant parameters exceeded their specified operational limits. This state was generally followed by a loss of engine power or system failure. |

Table 102: Near Midair Collision State Definition

| Near Midair Collision State | |
|---|---|
| Hazardous state where two or more aircraft almost collided with each other during flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 260: Near midair collision | The NTSB introduced this code in the post-2008 system to highlight situations where aircraft almost collided with each other. |

Table 103: Exceeding Helicopter Hover Performance State Definition

| Exceeding Helicopter Hover Performance State | |
|---|---|
| Hazardous state where the aircraft exceeds its design hover performance. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17310: Helicopter hover performance AND (“exceeded” OR “lack of” OR “deteriorated”) | I identified this code by searching the coding manual for the phrase “hover performance”. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 104: Exceeding Aircraft Takeoff Capability State Definition

| Exceeding Aircraft Takeoff Performance State | |
|---|---|
| Hazardous state where the aircraft exceeds its design takeoff performance. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17301: Aircraft takeoff capability AND (“exceeded” OR “inadequate” OR “deteriorated”) | I identified this code by searching the coding manual for the phrase “takeoff capability”. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 105: Exceeding Aircraft Landing Capability State Definition

| Exceeding Aircraft Landing Performance State | |
|---|---|
| Hazardous state where the aircraft exceeds its design landing performance. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17302: Aircraft landing capability AND (“exceeded” OR “inadequate” OR “deteriorated” OR “low”) | I identified this code by searching the coding manual for the phrase “landing capability”. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 106: Improper Lift-off State Definition

| Improper Lift-off State | |
|---|---|
| Hazardous state where the aircraft did not lift-off correctly. | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Improper Lift-off State | |
|---|---|
| 24533: Lift-off AND ("not attained" OR "not possible" OR "not corrected") | I identified this code by searching the coding manual for the phrase "lift-off". |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 107: Exceeding Aircraft Performance Limits State Definition

| Exceeding Aircraft Performance Limits State | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design performance capabilities. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17300: Aircraft performance (general) AND ("exceeded" OR "deteriorated" OR "vibration") | I identified this code by searching the coding manual for the phrase "aircraft performance".<br><br>The NTSB used this "general" code to indicate that the aircraft was operated beyond its design performance. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 108: Improper Operation of Rotorcraft State Definition

| Improper Operation of Rotorcraft State | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design performance capabilities. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24800: Rotorcraft operations AND ("improper" OR "excessive" OR "exceeded") | I identified this code by searching the coding manual for the phrase "rotorcraft operations".<br><br>The NTSB used this "general" code to indicate that the aircraft was not operated correctly by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 109: Exceeding Aircraft Yaw Performance State Definition

| Exceeding Aircraft Yaw Performance State | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design yaw performance capabilities. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17306: Yawing maneuvers (performance) AND ("exceeded" OR "deteriorated" OR "erratic") | I identified this code by searching the coding manual for derivatives of the word "yaw". |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 110: Exceeding Aircraft Engine-out Capability State Definition

| **Exceeding Aircraft Engine-out Capability State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its performance capabilities after the loss of engine power. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17304: Aircraft performance—engine out capability AND ("exceeded") | I identified this code by searching the coding manual for the phrase "engine out". |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 111: Exceeding Aircraft Crosswind Capability State Definition

| **Exceeding Aircraft Crosswind Performance State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design crosswind performance capabilities. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01061015XX: Maximum crosswind capability AND ("capability exceeded") | I identified this code by searching the coding manual for the "crosswind". |

Table 112: Exceeding Aircraft Configuration Capability State Definition

| **Exceeding Aircraft Configuration Capability State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design capabilities for a given configuration. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01061017XX: Configuration AND ("capability exceeded") | I identified this code by searching the coding manual for the word "configuration". |

Table 113: Improper Power-on Landing State Definition

| **Improper Power-on Landing State** | |
|---|---|
| Hazardous state where the pilot performs an improper landing with engine(s) operational. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24557: Power-on landing AND ("not possible" OR "not maintained" OR "uncontrolled" OR "improper") | I identified this code by searching the coding manual for the phrase "power-on landing". |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 114: Poor Interpersonal Relations State Definition

| **Poor Interpersonal Relations State** | |
|---|---|
| Hazardous state where the pilot has poor relations with his co-pilot/crew. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 31240: Interpersonal relations | I identified this code by searching the coding manual for the word "interpersonal". |

| Poor Interpersonal Relations State | |
|---|---|
| Hazardous state where the pilot has poor relations with his co-pilot/crew. | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 115: Runway Undershoot State Definition

| Runway Undershoot State | |
|---|---|
| Hazardous state where the aircraft landed short of the runway. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 390: Undershoot | I identified this code by searching the coding manual for the word “undershoot”. |
| **NTSB Codes (post-2008)** | **Notes** |
| 370: Landing area undershoot | I identified this code by searching the coding manual for the word “undershoot”. |

Table 116: Wheels-down Landing in Water State Definition

| Wheels-down Landing in Water State | |
|---|---|
| Hazardous state where the aircraft landed short of the runway. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 231: Wheels-down landing in water | I identified this code by searching the coding manual for the phrase “wheels-down”. |
| **NTSB Codes (post-2008)** | **Notes** |
| 095: Landing gear not configured | In the post-2008 system, the NTSB used this code to indicate situations where there were wheels-down landings in water and wheels-up landings. |

Table 117: On-ground Loss of Control State Definition

| On-ground Loss of Control State | |
|---|---|
| Hazardous state where the pilot fails to maintain control of aircraft heading and attitude when on the ground. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 260: On-ground loss of control | I identified this code by searching the coding manual for the phrase “loss of control” and “ground”. |
| **NTSB Codes (post-2008)** | **Notes** |
| 230: Loss of control on ground | I identified this code by searching the coding manual for the phrase “loss of control” and “ground”. |

Table 118: Improper Level-off State Definition

| Improper Level-off State |
|---|
| Hazardous state where the pilot fails to bring the helicopter to a level attitude (usually in preparation for a landing). |

| Improper Level-off State | |
|---|---|
| **NTSB Codes (pre-2008)** | **Notes** |
| 24534: Level-off AND (“improper” OR “not maintained” OR “misjudged” OR “not attained” OR “not possible” OR “delayed” OR “not obtained” OR “premature” OR “high” OR “inadequate” | I identified this code by searching the coding manual for the phrase “level-off”. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 119: Low Oil State Definition

| Low Oil State | |
|---|---|
| Hazardous state where the aircraft was operating with low oil level | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071020XX: Oil AND (“fluid level”) | I identified these codes by searching the coding manual for the words “oil”. I also included those instances that had the modifier “fluid level”.<br>I did not include codes corresponding to the oil system. |

Table 120: Low Coolant State Definition

| Low Coolant State | |
|---|---|
| **Hazardous state where the aircraft was operating with low coolant level** | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071025XX: Coolant AND (“fluid level”) | I identified these codes by searching the coding manual for the words “coolant”. I also included those instances that had the modifier “fluid level”. |

Table 121: Low Grease State Definition

| Low Grease State | |
|---|---|
| Hazardous state where the aircraft was operating with low grease level. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071035XX: Fuel AND (“fluid level”) | I identified these codes by searching the coding manual for the words “grease”. I also included those instances that had the modifier “fluid level”. |

Table 122: Inflight Collision with Terrain/Water/Object End State Definition

| Inflight Collision with Terrain/Water/Object State | |
|---|---|
| Hazardous state where the aircraft collided with terrain/water/object during flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 230: Inflight collision with terrain/water | I identified this code by searching the coding manual for the words "collision", "terrain", and "object". |
| 220: Inflight collision with object | |
| **NTSB Codes (post-2008)** | **Notes** |
| 470: Inflight collision with terrain/object | I identified this code by searching the coding manual for the words "collision", "terrain", and "object". The NTSB combined the codes for object and terrain in the post-2008 system. |

Table 123: Hard Landing End State Definition

| Hard Landing State | |
|---|---|
| Hazardous state where the aircraft landing gear impacted the ground with great force. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 200: Hard landing | I identified this code by searching the coding manual for the phrase "hard landing". |
| **NTSB Codes (post-2008)** | **Notes** |
| 092: Hard landing | I identified this code by searching the coding manual for the phrase "hard landing". |

Table 124: Forced/Emergency Landing End State Definition

| Forced/Emergency Landing State | |
|---|---|
| Hazardous state where the pilot is unable to choose the landing site and is forced to perform an emergency landing. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 180: Forced landing | I identified this code by searching the coding manual for the phrase "forced landing" and "emergency landing". This code is used interchangeably by the NTSB to indicate an emergency landing or emergency descent. |
| **NTSB Codes (post-2008)** | **Notes** |
| 440: Off-field emergency landing | I identified this code by searching the coding manual for the phrase "forced landing". |

Table 125: On-ground collision with Terrain/Water/Object End State Definition

| On-ground collision with Terrain/Water/Object State | |
|---|---|
| Hazardous state where the aircraft collided with terrain/water/object while operating on the ground. | |
| **NTSB Codes (pre-2008)** | **Notes** |

| On-ground collision with Terrain/Water/Object State | |
|---|---|
| 310: On ground/water collision with object | I identified this code by searching the coding manual for the phrase “on-ground” and the words “collision”, “terrain”, and “object”. |
| 320: On-ground/water collision with terrain | |
| 271: Collision between aircraft (other than midair) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 200: Ground collision | I identified this code by searching the coding manual for the words “ground” and “collision”. The NTSB used this code to indicate accidents that involved collision on the ground in the post-2008 system. |

Table 126: Propeller/Rotor Contact to Person End State Definition

| Propeller/Rotor Contact to Person State | |
|---|---|
| Hazardous state where rotating rotor/propeller blades make contact with a person, resulting in injuries. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 370: Propeller/rotor contact to person | I identified this code by searching the coding manual for the word “contact” and “person”. The NTSB used this code as end state to indicate that rotor/propeller blades made contact with a person during operation (generally while disembarking). |
| **NTSB Codes (post-2008)** | **Notes** |
| 081: Aircraft/propeller/rotor contact with person | I identified this code by searching the coding manual for the word “contact” and “person”. The NTSB used this code as end state to indicate that rotor/propeller blades made contact with a person during operation (generally while disembarking). |

Table 127: Dragged Wing/Rotor/Float End State Definition

| Dragged Wing/Rotor/Float State | |
|---|---|
| Hazardous state where the aircraft’s wing/rotor/float is dragged along the ground/water. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 160: Dragged wing/rotor/float/other | I identified this code by searching the coding manual for the phrase “dragged-wing”. |
| **NTSB Codes (post-2008)** | **Notes** |
| 093: Dragged wing/rotor/float/other | I identified this code by searching the coding manual for the phrase “dragged-wing”. |

Table 128: Nose Down/Over End State Definition

| **Nose Down/Over State** | |
|---|---|
| Hazardous state where the aircraft's nose makes contact with the ground/water/runway surface:<br>-without inverting the aircraft (nose down)<br>-and inverts the aircraft (nose over) | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 290: Nose down | I identified this code by searching the coding manual for the phrase "nose-down" and "nose-over". |
| 300: Nose over | |
| **NTSB Codes (post-2008)** | **Notes** |
| 096: Nose down/over | I identified this code by searching the coding manual for the phrase "nose-down" and "nose-over". The NTSB combined these codes into a single code in the post-2008 system. |

Table 129: Midair Collision End State Definition

| **Midair Collision State** | |
|---|---|
| Hazardous state where two or more aircraft collide during flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 270: Midair collision | Note that the midair collision code should appear in the end of the accident sequence in order to be classified as end state |
| **NTSB Codes (post-2008)** | **Notes** |
| 250: Midair collision | Note that the midair collision code should appear in the end of the accident sequence in order to be classified as end state |

Table 130: Ditching End State Definition

| **Ditching** | |
|---|---|
| Hazardous state where the crew makes a planned emergency landing in water. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 150: Ditching | I identified this code by searching the coding manual for the word "ditching". |
| **NTSB Codes (post-2008)** | **Notes** |
| 441: Ditching | I identified this code by searching the coding manual for the word "ditching". |

Table 131: Collision during Takeoff/Landing End State Definition

| **Collision during Takeoff/Landing State** | |
|---|---|
| Hazardous state where the aircraft collides with terrain/object during the takeoff or landing phase of flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 490: Collision during takeoff/landing | I identified this code by searching the coding manual for the words “collision” and “takeoff/landing”. |

Table 132: Fire/Explosion End State Definition

| **Fire/Explosion State** | |
|---|---|
| Hazardous state where the aircraft explodes or catches fire after impact with terrain/object. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 170: Fire | I identified this code by searching the coding manual for the words “fire” and “explosion”. These codes are classified as end states when they appear in the end of the accident sequence. |
| 171: Fire/explosion | |
| **NTSB Codes (post-2008)** | **Notes** |
| 170: Fire/smoke (post-impact) | I identified this code by searching the coding manual for the words “fire” and “explosion”. These codes are classified as end states when they appear in the end of the accident sequence. |
| 180: Explosion (post-impact) | |

Table 133: Abnormal Runway Contact End State Definition

| **Abnormal Runway Contact State** | |
|---|---|
| Hazardous state where the pilot failed to execute a correct landing (other than hard landing). | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 090: Abnormal runway contact | Examples for abnormal runway contact include bouncing, and then skidding before coming to rest. |

Table 134: Missing Aircraft End State Definition

| **Missing Aircraft State** | |
|---|---|
| Hazardous state where the aircraft was not recovered after the accident. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 420: Missing aircraft | I identified this code by searching the coding manual for the word “missing”. |

| Missing Aircraft State | |
|---|---|
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

# APPENDIX B. DEFINTIONS OF TRIGGERS

Table 135: Improper Maintenance Trigger Definition

| **Improper Maintenance** | |
|---|---|
| This trigger represents maintenance-related errors or violation | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24003: Aircraft service AND (“improper” OR “inadequate” OR “not corrected”) | I identified these codes by searching the coding manual for derivatives of the word “maintain” and “inspect”. I did not include the codes corresponding to maintaining aircraft control and maintenance computers. I also included the codes for aircraft service and installation. |
| 24704: Installation AND (“improper” OR “inadequate”) | |
| 24100–24124: Maintenance (hierarchy) AND (“improper” OR “inadequate” OR “not corrected” OR “not performed” OR “delayed” OR “not identified” OR “poor” OR “inattentive” OR “not possible” OR “information insufficient” OR “disregarded” OR “not followed” OR “not required” OR “not complied with” OR “overdue” OR “reduced” OR “incorrect” OR “not maintained” OR “excessive” OR inadvertent use of “ OR “not verified” OR “not approved” OR “intentional” OR “reversed” OR “low” OR “inaccurate” OR “note received” OR “not attained” | |
| **NTSB Codes (post-2008)** | **Notes** |
| 010105**YY**XX: Maintenance/inspections (hierarchy) | Here, **YY** represents that different maintenance actions that are recorded under the Maintenance/inspections hierarchy. **YY** ranges from “00: general” to “20: scheduled maintenance checks” |
| 020615**YY**XX: Inspection (hierarchy) | Here, **YY** represents that different maintenance actions that are recorded under the Inspection hierarchy. **YY** ranges from “00: general” to “20: scheduled/routine inspection” |
| 020620**YY**XX: Maintenance (hierarchy) | Here, **YY** represents that different maintenance actions that are recorded under the Inspection hierarchy. **YY** ranges from “00: general” to “35: installation” |
| 02062415XX: Record keeping-aircraft/maintenance logs | In addition to the subject codes and occurrences listed in this table, I used the following maintenance-related modifiers: (1) Incorrect service/maintenance, (2) not serviced/maintained, (3) inadequate inspection, and (4) not inspected |
| 04023025XX: Maintenance scheduling | |
| 04032020XX: Oversight of maintenance | |
| 04033025XX: Documentation/record keeping-maintenance records | |
| 030: Aircraft servicing event | |
| 040: Aircraft maintenance event | |
| 050: Aircraft inspection event | |

Table 136: Improper Inflight Planning/Decision-making Trigger Definition

| **Improper Inflight Planning/Decision-making** | |
|---|---|
| This trigger represents incorrect planning or decisions taken by the pilot(s) during flight | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24000: Planning/decision | I identified these codes by searching the coding manual for derivatives of the words “plan” and “decision”. I did not include the codes that corresponded to preflight planning and preparation. |
| 24010: Inflight planning/decision-making | |
| 24031: Judgment | |
| 60000: Improper decision | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02041510XX: Information processing/decision-identification/recognition | Unlike the pre-2008 system, which provided little insight into the types of actions that triggered hazardous states, the current system has subject codes such as “02041025XX: Delayed action”, “02041030: Lack of action”, and “02041035XX: Forgotten action/omission”. I present these codes as “one-to-one” codes. |
| 02041515XX: Information processing/decision—Understanding/comprehension | |
| 02041520XX: Information processing/decision-Decision making/judgment | |

Table 137: Improper Use of Collective Trigger Definition

| **Improper Use of Collective** | |
|---|---|
| This trigger represents the incorrect collective input by the pilot during flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23202: Collective AND (“improper use of” OR “excessive” OR “improper” OR “delayed” OR “not used” OR “not possible” OR “premature” OR “uncontrolled” OR “inadvertent activation” OR “inadequate” OR “inattentive” OR “inadvertent use” OR “abrupt” OR “attempted”) | I identified this code by searching the coding manual for the word “collective”.<br><br>Raising or lowering the collective control in a helicopter changes the pitch of the main rotor blades, resulting in a change in the amount of lift force generated by the main rotor. Incorrect use of collective can potentially result in a low RPM state for the system. |
| 23206: Lowering of collective AND (“delayed” OR “restricted” OR “abrupt” OR “premature”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 138: Improper Maneuvering Trigger Definition

| **Improper Maneuvering** | |
|---|---|
| This trigger represents sudden or incorrect maneuvering by the pilot during flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Improper Maneuvering | |
|---|---|
| 100: Abrupt maneuver | I identified these codes by searching the coding manual for the words “abrupt” and “maneuver |
| 24543: Maneuver AND (“excessive” OR “misjudged” OR “uncontrolled” OR “abrupt” OR “improper” OR “poor” OR “delayed” OR “premature” OR “inaccurate”) | |
| 24582: Evasive maneuver AND (“attempted” OR “performed” OR “intentional” OR “initiated”) | |
| 24501: Aerobatic (maneuver) AND (“performed”) | |
| 24537: Ground loop/swerve AND (“inadvertent”) | |
| 24583: Low altitude flight/maneuver AND (“not successful” OR “attempted” OR “required” OR “performed” OR “intentional” OR “initiated”) | |
| 24584: Maneuver to avoid obstructions AND (“misjudged” OR “intentional” OR “abrupt” OR “improper” OR “not performed”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 270: Abrupt maneuver | I identified these codes by searching the coding manual for the words “abrupt” and “maneuver”. |

Table 139: Improper Use of Throttle/Powerplant Controls Trigger Definition

| Improper Use of Throttle/Powerplant Controls | |
|---|---|
| This trigger represents incorrect use of throttle/powerplant controls by the pilot. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 22300: Powerplant controls AND (“improper use of“ OR “not understood” OR “not used” OR “inadvertent deactivation” OR “not selected”) | I identified these codes by searching the coding manual for the words “throttle/power”. I did not include the codes corresponding to the failure of throttle, engine, or powerplant components. |
| 22301: Throttle/power control AND (“improper use of“ OR “improper” OR “delayed” OR “reduced” OR “inadvertent activation” OR “inadvertent deactivation” OR “not maintained” OR “not used” OR “removed” OR “excessive” OR “not possible” OR “inadequate” OR “uncontrolled” OR “not set” OR “exceeded” OR “incorrect” OR “restricted”) | |
| 22303: Mixture control OR (“improper” OR “improper use of“ OR “improper deactivation” OR “inadvertent use”) | |
| 22314: Throttle/power control friction lock AND (“excessive”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057600XX: Aircraft power plant—Engine controls-general AND (“not used/operated” OR “incorrect use/operation”) | I identified these codes by searching the coding manual for the words “throttle/power”. I did not include the codes corresponding to the failure of throttle, engine, or powerplant components. |
| 01057602XX: Mixture control AND (“incorrect use/operation” OR “unintentional use/operation” OR “unnecessary use/operation”) | |
| 01057603XX: Power lever AND (“incorrect use/operation”) | |

Table 140: Improper Engine Shutdown Trigger Definition

| Improper Engine Shutdown | |
|---|---|
| This trigger represents incorrect shutdown of an engine. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 22309: Wrong engine shutdown AND (“performed”) | |

| Improper Engine Shutdown | |
|---|---|
| 23316: Engine shutdown OR (“inadvertent” OR “attempted” OR “performed” OR “simulated”) | I identified this codes by searching the coding manual for the word “shutdown”. |
| **NTSB Codes (post-2008)** | **Notes** |
| 140: Engine shutdown | I identified this codes by searching the coding manual for the word “shutdown”. |

Table 141: Improper Use of Altimeter Trigger Definition

| Improper Use of Altimeter | |
|---|---|
| This trigger represents the incorrect use/setting of the altimeter by the pilot. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23103: Altimeter setting AND (“improper” OR “incorrect”) | First, I searched for the words “altimeter”. Then, I included those modifiers that suggested some form of improper pilot action (e.g., improper altimeter setting). |
| 23107: Altimeter AND (“not set”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01023416XX: Aircraft systems-Navigation system-Altimeter-barometric/encoder AND (“not used/operated”) | First, I searched for the words “altimeter”. Then, I included those modifiers that suggested some form of improper pilot action (e.g., improper altimeter setting). |

Table 142: Improper Communication Trigger Definition

| Improper Communication | |
|---|---|
| This trigger represents incorrect communication by the pilot/crew | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24600: Communication with ATC AND (“inadequate” OR “improper”) | I identified these codes by searching the coding manual for derivatives of the words “communicate” and “instruction”. |
| 24601: Interpretation of instructions AND (“not understood” OR “confusing” OR “improper” OR “incorrect”) | |
| 24602: Instructions-written/verbal AND (“not understood” OR (not followed” OR “inadequate” OR “not obtained” OR “not verified” OR “inaccurate” OR “attempted” OR “disregarded”) | |
| 24608: Communication AND (“inadequate” OR “poor” OR “incorrect” OR “inaccurate” OR “not understood”) | |
| 24609: Communication-information AND (“not issued” OR “inadequate” OR “not available” OR “not obtained” OR “improper” OR “incorrect”) | |
| 24611: Radio communication AND (“inadequate” OR “delayed” OR “not used” | |
| 24621: Air/ground communication AND (“inadequate” OR “not available” OR “inaccurate” OR “disregarded” OR “initiated” OR “not performed” OR “poor”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02063510XX: Task performance—Communication—Lack of communication | I identified these codes by searching the coding manual |

| Improper Communication | |
|---|---|
| 02063515XX: Task performance—Communication—Accuracy of communication | for derivatives of the words “communicate” and “instruction”. |
| 02063538XX: Task performance—Communication—Issuing instructions | |

Table 143: Improper Use of Procedure or Directives Trigger Definition

| **Improper Use of Procedure or Directives** | |
|---|---|
| This trigger represents situation where the pilot/maintenance personnel failed to follow or disregarded the specified procedure | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24032: Procedures/directives AND (“not followed” OR “not complied with” OR “improper” OR “disregarded” OR “not performed” OR “poor” OR “not used” OR “misjudged” OR “improper use of”) | I identified these codes by searching the coding manual for the word “procedure”. I only included the modifier that suggested that procedure/directive was not followed. |
| 24016: Visual flight rules (VFR) procedures AND (“improper” OR “not followed” OR “not maintained”) | |
| 24018: Flight manuals AND (“not followed” OR “not complied with” OR “misjudged” OR “disregarded”) | |
| 24024: Instrument flight rules (IFR) procedure AND (“not followed” OR “not performed” OR “improper”) | |
| 24030: Checklist AND (“not followed” OR “not used” OR “not complied with” OR “not verified”) | |
| 24301: Dispatch procedure AND (“not followed”) | |
| 24545: Emergency procedure AND (“improper” OR “not followed” OR “not complied with” OR “not attained” OR “not selected” OR “poor” OR “disregarded” OR “inadequate” OR “delayed”) | |
| 24549: Starting procedure AND (“improper” OR “initiated” OR “attempted” | |
| 30000: Improper use of procedure | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02063032XX: Task performance—Use of equip/info—Use of policy/procedure | I identified these codes by searching the coding manual for the word “procedure”. I did not include the corresponding to availability or adequacy of procedures. |
| 02063020XX: Task performance—Use of equip/info—Use of manual | |
| 02063030XX: Task performance—Use of equip/info—Use of checklist | |

Table 144: Insufficient Procedure or Directives Trigger Definition

| **Insufficient Procedure or Directives** | |
|---|---|
| This trigger represents situations where the pilot(s) or maintenance personnel had procedures, directives, or manuals that did not have requisite information. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24032: Procedures/directives AND (“inadequate” OR “not issued” OR “poor”) | I identified these codes by searching the coding manual for the word “procedure”. I included those modifiers that suggested a lack of information in the procedures or directives. |
| 24017: Documentation AND (“inadequate”) | |
| 24018: Flight manuals AND (“inadequate” OR “improper” OR “inaccurate” OR “information insufficient”) | |
| 24030: Checklist AND (“inadequate” OR “improper” OR “poor”) | |
| 21001: Approach charts AND (“unavailable”) | |

| Insufficient Procedure or Directives | |
|---|---|
| 24609: Information AND ("inadequate" OR "not available" OR "not obtained" OR "not compiled with" OR "incorrect" OR "poor") | I also included the codes for where the pilot/maintenance personnel did not have enough information. |
| 24300: Dispatch AND ("improper") | |
| 24301: Dispatch procedure AND ("inadequate") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 04021000XX: Organizational issues—Management-Policy/procedure—General | I identified these codes by searching the coding manual for the word "procedure". |
| 04021010XX: Availability of policy/procedure | |
| 04021015XX: Adequacy of policy/procedure | |

Table 145: Improper Use of Aerial Application/External Load Equipment Trigger Definition

| Improper Use of Aerial Application/External Load Equipment | |
|---|---|
| This trigger represents the improper use of external load equipment. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17400: Aerial application equipment (general) AND ("not removed") | I identified this code by searching the coding manual for the phrases "aerial application", "external load" and "pickup equipment".<br><br>I exclude the codes that refer to snagging/entanglement of the external load equipment. |
| 17500: Towing/advertising/external load equipment AND ("not secured" OR "reversed") | |
| 17503: Pickup equipment AND ("deployed inadvertently") | |
| 17505: External load sling/harness AND ("not dumped" OR "not disconnected") | |
| 17506: External load cable/hook AND ("not removed") | |
| 17507: External load release system AND ("not activated") | |
| 23311: External load equipment AND ("improper use" OR "improper" OR "not approved" OR "misjudged" OR "not removed" OR "encountered") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01022551XX: Equipment/furnishings—Agricultural/external load system | I identified this code by searching the coding manual for the phrases "external load" and "pickup equipment". I exclude the codes that refer to snagging/entanglement of the external load equipment. |
| 480: External load event (rotorcraft) | |

Table 146: Fuel Contamination/Exhaustion Trigger Definition

| Fuel Contamination/Exhaustion | |
|---|---|
| This trigger represents fuel contamination or exhaustion | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17001: Fluids-Fuel AND ("exhaustion" OR "starvation" OR "improper" OR "water" OR "contamination" OR "contamination-water" OR "contamination other than water" OR "leak" OR "flow restricted" OR "incorrect" OR "obstructed" OR "dumped" OR "movement restricted" OR "fumes" OR "fire" OR "blocked (partial)" OR "blocked (total)" OR "excessive flow/output") | I identified this code by searching the coding manual for the word "fuel". I exclude codes that refer to the failure of the fuel system or low fuel level. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071010XX: Fluids/miscellaneous hardware-fuel AND ("fluid management" OR "fuel condition" OR "inadequate inspection" OR | I identified this code by searching the coding manual |

| Fuel Contamination/Exhaustion | |
|---|---|
| This trigger represents fuel contamination or exhaustion | |
| "not serviced/maintained" OR "fluid type" OR "incorrect service/maintenance") | for the word "fuel". I exclude codes that refer to the failure of the fuel system or low fuel level. |
| 191: Fuel starvation | |
| 192: Fuel exhaustion | |
| 193: Fuel contamination | |

Table 147: Landing Gear Collapse Trigger Definition

| **Landing Gear Collapse** | |
|---|---|
| This trigger represents landing gear collapse | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 191: Main gear collapsed | I identified these code by searching the coding manual for the phrase "gear collapse". |
| 192: Nose gear collapsed | |
| 193: Tail gear collapsed | |
| 194: Complete gear collapsed | |
| **NTSB Codes (post-2008)** | **Notes** |
| 094: Landing gear collapse | I identified this code by searching the coding manual for the phrase "gear collapse". |

Table 148: Aerial Application/External Load Equipment Failure/Entanglement Trigger Definition

| **Aerial Application/External Load Equipment Failure/Entanglement Failure** | |
|---|---|
| This trigger represents the failure or snagging of external load equipment | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17400: External load equipment (general) AND ("snagged" OR "entangled" OR "improper" OR "failure-total") | I identified these codes by searching the coding manual for the phrases "external load" and "pickup equipment".<br><br>I defined this trigger by grouping these when they indicated external load system failure/entanglement with the rotor system. |
| 17401: Spray/dusting equipment AND ("blocked (total)" OR "blocked (partial)" OR "corroded" OR "extraneous" OR "malfunction" OR "overload") | |
| 17500: Towing/advertising/external load equipment AND ("snagged" OR "entangled") | |
| 17503: Pickup equipment AND ("inadequate" OR "failure-total" OR "incorrect" OR "separation" OR "movement restricted") | |
| 17505: External load sling/harness AND ("entangled" OR "slipped" OR "inadequate" OR "separation" OR "improper" OR "shifted" OR "oscillation") | |
| 17506: External load cable/hook AND ("entangled" OR "snagged" OR "failure" OR "blade strike" OR "binding" OR "separation" OR "incorrect" OR "fouled") | |
| 17507: External load release system AND ("inoperative" OR "jammed" OR "malfunction") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01022551XX: Equipment/furnishings—Agricultural/external load system AND ("malfunction" OR "inoperative") | I identified these codes by searching the coding manual for the phrases "external load" and "pickup equipment". |
| 410: External load event (rotorcraft) | |

| Aerial Application/External Load Equipment Failure/Entanglement Failure | |
|---|---|
| This trigger represents the failure or snagging of external load equipment | |
| | I defined this trigger by grouping these when they indicated external load system failure/entanglement with the rotor system. |

Table 149: Improper Loading/Securing of Cargo Trigger Definition

| **Improper Loading/Securing of Cargo** | |
|---|---|
| This trigger represents incorrect loading or securing of cargo by the pilot or ground personnel. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24035: Security of cargo AND ("inadequate" OR "not verified" OR "inaccurate") | I identified these codes by searching the coding manual for the word "cargo". |
| 24040: Loading of cargo AND ("excessive" OR "improper") | |
| 23317: Load tie-down/security AND ("inadequate" OR "improper") | |
| 17116: Cargo/baggage AND ("not secured" OR "loose") | |
| 120: Cargo shift | |
| **NTSB Codes (post-2008)** | **Notes** |
| No codes available | |

Table 150: Improper Use of Deicing System Trigger Definition

| **Improper Use of Deicing System** | |
|---|---|
| This trigger represents improper use of the deicing system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 12305: Anti-ice/deice-carburetor heat AND ("not engaged") | These codes represent the improper use of the deicing system |
| 22600: Anti-ice/deice system AND("not used" OR "improper use of" OR "not complied with") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01023020XX: Ice/rain protection system-intake anti-ice/deice AND ("not used/operated") | This code represents the improper use of the deicing system. |

Table 151: Poor Choice of Landing/Takeoff Area Trigger Definition

| **Poor Choice of Landing/Takeoff Area** | |
|---|---|
| This trigger represents a poor choice of landing/takeoff/taxi area by the pilot | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24028: Wrong runway AND ("selected") | This code indicates that the pilot chose an incorrect/inappropriate landing terrain. |
| 24029: Unsuitable terrain or takeoff/landing/taxi area AND ("selected" OR "attempted" OR "not verified" OR "not identified" OR "encountered" OR "not obtained" OR "misjudged") | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 152: Improper Use of Protective Covering Trigger Definition

| **Improper Use of Protective Covering** | |
|---|---|
| This trigger represents the improper use of protective covering for the aircraft | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17124: Miscellaneous-protective covering | These codes represent the improper use of protective covering for the aircraft. |
| 23313: Aircraft protective covering AND (“not used” OR “not available” OR “unavailable” OR “disregarded”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 153: Improper Fuel Grade Trigger Definition

| **Improper Fuel Grade** | |
|---|---|
| This trigger represents water-contaminated fuel/oil | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17008: Fluids-Fuel grade | This code represents the use of improper type of fuel. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071010XX: Fluids/miscellaneous hardware-fuel | These codes represents the use of improper type of fuel. |
| 194: Wrong fuel | |

Table 154: Improper Aborted landing/takeoff Trigger Definition

| **Improper Aborted landing/takeoff** | |
|---|---|
| This trigger represents the entanglement of the helmet. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24502: Abort | I identified these codes by searching for derivatives of the word “abort”. |
| 24504: Aborted landing | |
| 24505: Aborted takeoff | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 155: Improper Touchdown Trigger Definition

| **Improper Touchdown** | |
|---|---|
| This trigger represents an improper touchdown by the pilot. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24531: Proper touchdown point | I identified these codes by searching for the word “touchdown”. |
| 24567: Touchdown | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 156: Improper use of Equipment (Unspecified) Trigger Definition

| **Improper use of Equipment (Unspecified)** | |
|---|---|
| This trigger represents improper use of unspecified equipment. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24700: Miscellaneous | The NTSB used this code suggest improper use of aircraft equipment, but did not |
| 24702: Equipment—other | |
| 23300: Miscellaneous equipment | |
| 40000: Improper use of equipment/aircraft | |

| Improper use of Equipment (Unspecified) | |
|---|---|
| This trigger represents improper use of unspecified equipment. | |
| | specify the nature of equipment in the codes. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 157: Warning/Safety System Failure Trigger Definition

| Warning/Safety System Failure | |
|---|---|
| This trigger represents the improper use of the auxiliary power unit. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 13107: Warning system | This trigger indicates the failure of warning systems |
| 13108: Safety system | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 158: Improper Action (Unspecified) Definition

| Improper Action (Unspecified) | |
|---|---|
| This trigger represents the failure of the oil system. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02040000XX: Action/decision—general—general | These codes are part of the action/decision hierarchy.<br><br>However, I define them separately as they do not indicate the type of action (e.g., delayed) unlike other action-triggers. |
| 02041000XX: Action/decision—Action—general | |
| 02041015XX: Incorrect action performance | |

Table 159: Improper Gear Position Trigger Definition

| Improper Gear Position | |
|---|---|
| This trigger represents failure of the pilot extend/retract the landing gear. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 196: Gear not extended | I identified these codes by searching for derivatives of the word “retract” and “extend” along with the phrase “landing gear”.<br><br>I also included the codes associated with the subject code “22000: Landing gear” and modifiers that indicated improper gear use/position. |
| 197: Gear not retracted | |
| 198: Gear retracted on ground | |
| 22000: Landing gear AND (“misjudged” OR “not selected”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 160: Fuselage/Wing Failure Trigger Definition

<table>
<tr><th colspan="2">Fuselage/Wing Failure</th></tr>
<tr><td colspan="2">This trigger represents the failure of fuselage/wing components.</td></tr>
<tr><td>NTSB Codes (pre-2008)</td><td>Notes</td></tr>
<tr><td>10000: Fuselage (general)</td><td rowspan="11">I identified these codes by searching the coding manual for the words “fuselage” and “wing” in the NTSB hierarchies.</td></tr>
<tr><td>10001: Crew compartment</td></tr>
<tr><td>10003: cabin</td></tr>
<tr><td>10006: skin</td></tr>
<tr><td>10007: longeron</td></tr>
<tr><td>10008: attachment</td></tr>
<tr><td>10010: fairing</td></tr>
<tr><td>10111: Winglet</td></tr>
<tr><td>10200: Nacelle/pylon (general)</td></tr>
<tr><td>10203: plate</td></tr>
<tr><td>10207: Fairing</td></tr>
<tr><td>NTSB Codes (post-2008)</td><td>Notes</td></tr>
<tr><td>01035302XX: Fuselage-Rotorcraft tail boom</td><td rowspan="6">I identified these codes by searching the coding manual for the words “fuselage” and “wing” in the NTSB hierarchies.</td></tr>
<tr><td>01035310XX: Fuselage main structure</td></tr>
<tr><td>01035311XX: Frames (main fuselage)</td></tr>
<tr><td>01035340XX: Fuselage attach fittings system</td></tr>
<tr><td>01035343XX: Gear attach fittings on fuselage</td></tr>
<tr><td>01035400XX: Nacelles/pylons structure (general)</td></tr>
</table>

Table 161: Flight Control Surfaces/Attachments Failure Trigger Definition

<table>
<tr><th colspan="2">Flight Control Surfaces/Attachments Failure</th></tr>
<tr><td colspan="2">This trigger represents the failure of fuselage/wing components.</td></tr>
<tr><td>NTSB Codes (pre-2008)</td><td>Notes</td></tr>
<tr><td>10300: Flight control surfaces/attachments</td><td rowspan="2">I identified these codes by searching the coding manual for the phrase “flight control” in the NTSB hierarchies. I exclude the codes under the “flight control system” hierarchy.</td></tr>
<tr><td>10313: Flight control, rudder</td></tr>
<tr><td>NTSB Codes (post-2008)</td><td>Notes</td></tr>
<tr><td>No code available</td><td></td></tr>
</table>

Table 162: Landing Gear Failure Trigger Definition

<table>
<tr><th colspan="2">Landing Gear Failure</th></tr>
<tr><td colspan="2">This trigger represents the failure of the landing gear.</td></tr>
<tr><td>NTSB Codes (pre-2008)</td><td>Notes</td></tr>
<tr><td>10400: Landing gear</td><td rowspan="7">I identified these codes by searching the coding manual for the words “gear” in the NTSB hierarchies.</td></tr>
<tr><td>10401: Main gear</td></tr>
<tr><td>10402: Main gear shock absorbing strut</td></tr>
<tr><td>10403: Main gear strut</td></tr>
<tr><td>10404: Main gear attachment</td></tr>
<tr><td>10405: Nose gear</td></tr>
<tr><td>10406: Nose gear assembly</td></tr>
</table>

| Landing Gear Failure | |
|---|---|
| This trigger represents the failure of the landing gear. | |
| 10413: Ski assembly | |
| 10414: Float assembly | |
| 10417: Skid assembly | |
| 10418: Normal brake system | |
| 10425: Steering system | |
| 10431: Main gear strut scissors | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01023200XX: Landing gear system (general) | I identified these codes by searching the coding manual for the word "gear" in the NTSB hierarchies. |
| 01023210XX: Main landing gear | |
| 01023211XX: Main landing gear attachment section | |
| 01023213XX: Main gear strut/axle/truck | |
| 01023270XX: Auxiliary gear | |

Table 163: Door/Window Failure/Contamination Trigger Definition

| Door/Window Failure/Contamination | |
|---|---|
| This trigger represents the failure of doors/windows, and contamination of windows | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 10500: Door (general) | I identified these codes by searching the coding manual for the word "door" and "window" in the NTSB hierarchies. |
| 10502: Exterior crew door | |
| 10503: Passenger door | |
| 10505: Cargo/baggage door | |
| 10506: Service door | |
| 10510: Inspection door | |
| 10601: Window-flight compartment window/windshield | |
| 10602: Cabin window | |
| 10603: Door-window (window in door) | |
| 10604: Inspection/observation window | |
| 10605: Canopy window | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01035200XX: Doors (general) | I identified these codes by searching the coding manual for the word "door" and "window" in the NTSB hierarchies. |
| 01035210XX: Passenger/crew doors | |
| 01035240XX: Service doors | |
| 01035610XX: Windows-flight compartment windows | |

Table 164: Flight Control System Failure Trigger Definition

| Flight Control System Failure | |
|---|---|
| This trigger represents the failure of flight control system components | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 10700: Flight control system (general) | I identified these codes by searching the coding manual for the phrase "flight control system" in the NTSB hierarchies. These codes refer to the failure of flight the control system. |
| 10708: Stabilator control | |
| 10711: Boost system | |
| **NTSB Codes (post-2008)** | **Notes** |

| Flight Control  System Failure | |
|---|---|
| This trigger represents the failure of flight control system components | |
| 01022700XX: Flight control system (general) | I identified thee codes by searching the coding manual for the phrase "flight control system" in the NTSB hierarchies.<br>These codes refer to the failure of flight the control system. |
| 01022701XX: Control column section | |
| 01022770XX: Gust lock or damper | |

Table 165: Improper Use of Flight Control System Trigger Definition

| Improper Use of Flight Control System | |
|---|---|
| This trigger represents the improper use of the flight control system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01022700XX: Flight control system (general) AND ("incorrect use/operation" OR "unintentional use/operation") | I identified these codes by searching the coding manual for the phrase "flight control system" in the NTSB hierarchies. |
| 01022770XX: Gust lock or damper AND ("incorrect use/operation") | |

Table 166: Stabilizer System Trigger Definition

| Stabilizer System Failure | |
|---|---|
| This trigger represents the failure of stabilizer system components | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 10800: Stabilizer (general) | I identified these codes by searching the coding manual for the word "stabilizer" in the NTSB hierarchies.<br>Each of these codes indicated failure of the stabilizer system. |
| 10802: Horizontal stabilizer attachment | |
| 10803: Vertical stabilizer surface | |
| 10804:: Vertical stabilizer attachment | |
| 10805:Horizontal stabilizer | |
| 10807: Vertical stabilizer | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01035500XX: Empennage structure (general) | I included this code as the empennage is an analogy for vertical and horizontal stabilizer for an aircraft.<br>This code indicated failure of the stabilizer system. |

Table 167: Rotor Drive System Failure Trigger Definition

| Rotor Drive System Failure | |
|---|---|
| This trigger represents the failure of stabilizer system components | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 11000: Rotor drive system (general) | I identified these codes by searching the coding manual |
| 11001: engine to transmission drive | |
| 11002: Main rotor mast (drive shaft) | |

| **Rotor Drive System Failure** | |
|---|---|
| This trigger represents the failure of stabilizer system components | |
| 11003: Freewheeling sprag unit | for the phrase “rotor drive” in the NTSB hierarchies.<br><br>Each of these codes represents the failure of a specific part of the rotor drive system |
| 11004: Freewheeling unit (other) | |
| 11005: Clutch assembly | |
| 11006: Main gearbox/transmission | |
| 11007: Combining gearbox | |
| 11008: Intermediate gearbox (42 deg.) | |
| 11009: Tail rotor gearbox (90 deg.) | |
| 11011: Tail rotor drive shaft | |
| 11013: Oil cooler drive shaft | |
| 11014: Tail rotor drive shaft bearing | |
| 11015: Main rotor driven pulley | |
| 11016: Main rotor driving pulley | |
| 11018: Main rotor drive belt | |
| 11019: Isolation link | |
| 11021: Tail rotor drive shaft coupling | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01046300XX: Main rotor drive (general) | I identified these codes by searching the coding manual for the phrase “rotor drive” in the NTSB hierarchies.<br><br>Each of these codes represents the failure of a specific part of the rotor drive system |
| 01046310XX: Engine/transmission coupling | |
| 01046330XX: Main rotor trans mount | |
| 01046500XX: Tail rotor drive system (general) | |
| 01046510XX: Tail rotor drive shaft | |
| 01046520XX: Tail rotor gear box | |

Table 168: Rotorcraft Flight Control System Failure Trigger Definition

| **Rotorcraft Flight Control System Failure** | |
|---|---|
| This trigger represents the failure of stabilizer system components | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 11100: Rotorcraft flight control system | I identified these codes by searching the coding manual for the phrase “rotorcraft flight control system” in the NTSB hierarchies.<br>Each of these codes represents the failure of a specific part of the rotorcraft flight control system |
| 11101: Primary servo | |
| 11103: Cyclic trim | |
| 11104: Collective trim | |
| 11107: Tail rotor servo | |
| 11110: NOTAR | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No codes available | |

Table 169: Rotor System Failure Trigger Definition

| **Rotor System Failure** | |
|---|---|
| This trigger represents the failure of rotor system components | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 11200: Main rotor (general) | I identified these codes by searching the coding manual |
| 11201:  Main rotor blade | |

| Rotor System Failure | |
|---|---|
| This trigger represents the failure of rotor system components | |
| 11202: Main rotor blade spar | for the phrase "rotor system" in the NTSB hierarchies.<br><br>Each of these codes represents the failure of a specific part of the rotor system. |
| 11203: Main rotor blade skin | |
| 11206: Main rotor blade abrasion strip | |
| 11207: Main rotor blade cuff | |
| 11208: tail rotor blade | |
| 11209: tail rotor blade spar | |
| 11211: tail rotor blade abrasion strip | |
| 11212: tail rotor blade cuff | |
| 11213: Main rotor hub | |
| 11214: Main rotor hub yoke (spindle) | |
| 11215: Main rotor hub grip (sleeve) | |
| 11217: Main rotor hub lead-lag stop/damper | |
| 11218: Main rotor hub stop (static/dynamic) | |
| 11219: Main rotor hub flapping hinge/stop(s) | |
| 11221: Main rotor hub pillow block | |
| 11222: Tail rotor hub | |
| 11223: Tail rotor hub counterweight | |
| 11224: Tail rotor hub pitch link | |
| 11225: Tail rotor hub pitch change mechanism | |
| 11226: Tail rotor hub pitch actuating shaft | |
| 11227: stabilizer bar | |
| 11228: rotor vibration absorber | |
| 11229: Main rotor blade balance weights | |
| 11230: Tail rotor blade balance weights | |
| 11231: Main rotor hub retaining nut | |
| 11232: Tail rotor hub retaining nut | |
| 11233: Main rotor blade retaining pin/bolt | |
| 11234: Main rotor blade drag brace | |
| 11235: Main rotor | |
| 11236: star flex arm | |
| 11237: Tail rotor | |
| 11238: Main rotor tension torsion bar | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01046200XX: Main rotor system (general) | I identified these codes by searching the coding manual for the phrase "rotor system" in the NTSB hierarchies.<br><br>Each of these codes represents the failure of a specific part of the rotor system. |
| 01046210XX:Main rotor blade system | |
| 01046220XX: Main rotor head system | |
| 01045230XX: Main rotor mast/swashplate | |
| 01046400XX: Tail rotor (general) | |
| 01046410XX: Tail rotor blade | |
| 01046420XX: Tail rotor head | |

Table 170: Airframe Component Failure Trigger Definition

| Airframe Component Failure | |
|---|---|
| This trigger represents the failure of specific airframe components | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 11300: Miscellaneous-airframe | Here, I grouped the different airframe/hardware-related codes that the NTSB classified as "miscellaneous". |
| 11301: Airframe | |
| 11302: Empennage | |
| 11303: Bolt/nut/fastener/clamp/spring | |

| Airframe Component Failure | |
|---|---|
| This trigger represents the failure of specific airframe components | |
| 11304: Dowel/pin | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071430XX: Miscellaneous hardware—fasteners | Here, I grouped the different airframe/hardware-related codes that the NTSB classified as "miscellaneous". |
| 01071400XX: Miscellaneous hardware (general) | |
| 01071410XX: Hoses and tubes | |

Table 171: Electrical System Failure Trigger Definition

| Electrical System Failure | |
|---|---|
| This trigger represents the failure of electrical system components | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 12000: Electrical system (general) | Each of these codes represent the failure of a specific component in the electrical system.<br><br>I excluded the modifiers that indicated incorrect use of the electrical system (and used them in a separate trigger) |
| 12001: Battery | |
| 12003: Voltmeter | |
| 12004: Generator | |
| 12005: Alternator | |
| 12013: Electric wiring | |
| 12015: Electric switch | |
| 12017: Circuit breaker | |
| 12019: Drive/belt | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01022430XX: Electrical power system-DC generation system | Each of these codes represent the failure of a specific component in the electrical system.<br><br>I excluded the modifiers that indicated incorrect use of the electrical system (and used them in a separate trigger) |
| 01022440XX: External power system | |

Table 172: Improper Use of Electrical System Trigger Definition

| Improper Use of Electrical System | |
|---|---|
| This trigger represents the improper use of the electrical system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 22400: Electrical system AND ("inadvertent deactivation") | I identified this code by searching the coding manual for the words "electrical" and "system".<br><br>Note that I used the AND logic to associate the electrical system code with the "inadvertent activation" modifier. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01022430XX: Electrical power system-DC generation system | |

| Improper Use of Electrical System | |
|---|---|
| This trigger represents the improper use of the electrical system | |
| 01022440XX: External power system | |

Table 173: Hydraulic System Failure Trigger Definition

| **Hydraulic System Failure** | |
|---|---|
| This trigger represents the failure of hydraulic system components | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 12100: Hydraulic system (general) | I identified these codes by searching the coding manual for the words "hydraulic" and "system in the NTSB hierarchies.<br><br>These codes correspond to the failure of the hydraulic system and not its improper use. |
| 12102: Pump | |
| 12104: Reservoir | |
| 12105: Hydraulic line | |
| 12113: Filter | |
| 12114: Actuator | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01022900XX: Hydraulic power system (general) | |
| 01022910XX: Hydraulic main system | |

Table 174: Improper Use of Hydraulic System Trigger Definition

| **Improper Use of Hydraulic System** | |
|---|---|
| This trigger represents the improper use of the hydraulic system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 12100: Hydraulic system (general) AND ("disabled") | I identified these codes by searching the coding manual for the words "hydraulic" and "system" in the NTSB hierarchies.<br>Note that I used the AND logic to associate the hydraulic system codes with modifiers that suggest incorrect use. |
| 12102: Pump | |
| 12104: Reservoir | |
| 12105: Hydraulic line | |
| 12113: Filter | |
| 12114: Actuator | |
| 22500: Hydraulic system AND ("inadvertent deactivation") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01022900XX: Hydraulic power system (general) AND ("incorrect use/operation") | |

Table 175: Navigation Instrument Failure Trigger Definition

| **Navigation Instrument Failure** | |
|---|---|
| This trigger represents the failure of navigation instruments | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 12201: Flight/navigation instruments—altimeter AND ("inadequate") | I identified these codes by searching the coding manual for the words "navigation" and "system" in the NTSB hierarchies. |
| 12202: Radio AND ("failure-partial") | |
| 12204: Turn and bank indicator AND ("inoperative") | |
| 12206: Attitude indicator AND ("inoperative") | |
| 12210: Compass AND ("inoperative") | |

| Navigation Instrument Failure | |
|---|---|
| This trigger represents the failure of navigation instruments | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01023416XX: Navigation system—Altimeter, barometric/encode | I identified these codes by searching the coding manual for the words “navigation” and “system” in the NTSB hierarchies. |

Table 176: Deicing System Failure Trigger Definition

| Deicing System Failure | |
|---|---|
| This trigger represents the failure of the deicing system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 12300: Anti-ice/deice system (general) AND (“leak”) | I identified these codes by searching the coding manual for the word “deice” in the NTSB hierarchies. |
| 12303: Anti-ice/deice system-windshield AND (“not installed”) | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 177: Engine Assembly Failure Trigger Definition

| Engine Assembly Failure | |
|---|---|
| This trigger represents the failure of engine assembly components | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 14000: Engine assembly (general) | I identified these codes by searching the coding manual for the phrase “engine assembly” in the NTSB hierarchies. Each of these codes represent failure of a specific part of the engine assembly. |
| 14001: Bearing | |
| 14002: Camshaft | |
| 14003: Crankcase | |
| 14004: Crankshaft | |
| 14006: Connecting rod | |
| 14007: Cylinder | |
| 14008: Piston | |
| 14009: Push rod | |
| 14010: Ring | |
| 14011: valve-intake | |
| 14012: Blower/impeller/integral supercharger | |
| 14013: Mount | |
| 14014: Engine assembly-other | |
| 14015: Connecting rod bolt | |
| 14016: Valve-exhaust | |
| 14017: Rocker arm/tappet | |
| 14019: Valve keeper | |
| 14020: Crankshaft counterweights/vibration damper | |
| 14022: Connecting rod cap | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01058300XX: Engine (reciprocating) (general) | I identified these codes by searching the coding manual for the phrase “engine |
| 01058520XX: Reciprocating engine power section | |
| 01058530XX: Reciprocating engine cylinder section | |

| Engine Assembly Failure | |
|---|---|
| This trigger represents the failure of engine assembly components | |
| | assembly" in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific part of the engine assembly. |

Table 178: Compressor Assembly Failure Trigger Definition

| **Compressor Assembly Failure** | |
|---|---|
| This trigger represents the failure of the compressor assembly | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 14100: Compressor assembly (general) | I identified these codes by searching the coding manual for the phrase "compressor assembly" in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific part of the compressor assembly. |
| 14101: Casting | |
| 14102: Stator vane retainer | |
| 14103: Rotor disc | |
| 14104: Blade | |
| 14105: Blade retention | |
| 14107: Impeller | |
| 14109: Air seal | |
| 14113: Stator vane | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057230XX: Engine (turbine/turboprop)—Compressor section | In the post-2008 system, I identified the code corresponding to compressor failure by searching for the word "compressor".<br><br>Each of these codes represent failure of a specific part of the compressor assembly. |

Table 179: Combustion Assembly Failure Trigger Definition

| **Combustion Assembly Failure** | |
|---|---|
| This trigger represents the failure of the combustion assembly | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 14200: Combustion assembly (general) | I identified these codes by searching the coding manual for the phrase "combustion assembly" in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific part of the combustion assembly. |
| 14201: Combustion liner | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057240XX: Engine (turbine/turboprop)—Combustion section | In the post-2008 system, I identified the code |

| Combustion Assembly Failure | |
|---|---|
| This trigger represents the failure of the combustion assembly | |
| | corresponding to compressor failure by searching for the word “combustion”.<br><br>Each of these codes represent failure of a specific part of the combustion assembly. |

Table 180: Turbine Assembly Failure Trigger Definition

| Turbine Assembly Failure | |
|---|---|
| This trigger represents the failure of the turbine assembly | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 14300: Turbine assembly (general) | I identified these codes by searching the coding manual for the phrase “combustion assembly” in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific part of the turbine assembly. |
| 14302: Seal | |
| 14303: Shroud | |
| 14304: Ring | |
| 14305: Nozzle | |
| 14308: Turbine wheel | |
| 14309: Turbine blade | |
| 14311: Air seal | |
| 14313: Shaft | |
| 14314: Shaft bearing | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057250XX: Engine (turbine/turboprop)—Turbine section | In the post-2008 system, I identified the code corresponding to compressor failure by searching for the word “turbine”. |

Table 181: Exhaust System Failure Trigger Definition

| Exhaust System Failure | |
|---|---|
| This trigger represents the failure of the exhaust assembly | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 14400: Exhaust system (general) | I identified these codes by searching the coding manual for the phrase “exhaust system” in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific part of the exhaust system. |
| 14401: Manifold/pipe | |
| 14405: Clamp | |
| 14406: Stack | |
| 14408: End plate | |
| 14411: Probe | |
| 14415: External supercharger | |
| 14416: Turbocharger | |
| 14419: Waste gate | |
| **NTSB Codes (post-2008)** | **Notes** |
| 011057800XX: Engine exhaust (general) | I identified this code by searching the coding manual for the phrase “exhaust |

| Exhaust System Failure | |
|---|---|
| This trigger represents the failure of the exhaust assembly | |
| | system” in the NTSB hierarchies. |

Table 182: Propeller System Failure Trigger Definition

| **Propeller System Failure** | |
|---|---|
| This trigger represents the failure of the propeller | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 14501: Propeller system/accessories-blade | I identified these codes by searching the coding manual for the phrase “propeller system” in the NTSB hierarchies. |
| 14513: Planetary gear | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 183: Accessory Drive Assembly Failure Trigger Definition

| **Accessory Drive Assembly Failure** | |
|---|---|
| This trigger represents the failure of the accessory drive assembly | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 14700: Accessory drive assembly (general) | I identified these codes by searching the coding manual for the phrase “accessory drive” in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific part of the accessory drive system. |
| 14705: Drive shaft | |
| 14706: Drive bearing | |
| 14707: Drive gear | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057260XX: Engine (turbine/turboprop)—Accessory drives | I identified these codes by searching the coding manual for the phrase “accessory drive” in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific part of the accessory drive system. |

Table 184: Ignition System Failure Trigger Definition

| **Ignition System Failure** | |
|---|---|
| This trigger represents the failure of the ignition system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 14800: Ignition system (general) | I identified these codes by searching the coding manual |
| 14801: Magneto | |

| Ignition System Failure | |
|---|---|
| This trigger represents the failure of the ignition system | |
| 14803: Spark plug | for the word "ignition" in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific part of the ignition system. |
| 14805: Low tension wiring | |
| 14806: High tension wiring | |
| 14808: Ignition harness | |
| 14809: Ignition switch | |
| 14810: Ignition lead | |
| 14813: Magneto grounding lead (p-lead) | |
| 14814: Auto re-light system | |
| 14815: Ignition points | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057414XX: Ignition system—magneto/distributor | I identified these codes by searching the coding manual for the word "ignition" in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific part of the ignition system. |
| 01057421XX: Spark plugs/igniters | |

Table 185: Engine Accessories Failure Trigger Definition

| Engine Accessories Failure | |
|---|---|
| This trigger represents the failure of engine accessories | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 14900: Engine accessories (general) | I identified these codes by searching the coding manual for the phrase "engine accessories" in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific engine accessories |
| 14906: Engine starter | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 186: Bleed Air System Failure Trigger Definition

| Bleed Air System Failure | |
|---|---|
| This trigger represents the failure of the bleed air system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 15000: Bleed air system (general) | I identified these codes by searching the coding manual for the phrase "bleed air" in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific part of the bleed air system. |
| 15001: Valve | |
| 15002: Sensitive valve | |
| 15003: Actuator | |
| 15004: Governor | |
| 15005: Lines | |
| 15006: Fittings | |

| Bleed Air System Failure | |
|---|---|
| This trigger represents the failure of the bleed air system | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057500XX: Engine bleed air system (general) | I identified this code by searching the coding manual for the phrase "bleed air" in the NTSB hierarchies.<br><br>Each of these codes represent failure of a specific part of the bleed air system. |

Table 187: Fuel System Failure/Contamination Trigger Definition

| Fuel System Failure/Contamination | |
|---|---|
| This trigger represents the failure/contamination of the fuel system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 15100: Fuel system (general) | I identified these codes by searching the coding manual for the phrase "fuel system" in the NTSB hierarchies.<br><br>Each of these codes represent the failure/contamination of a specific component in the fuel system.<br><br>Note that this trigger definition does not include the improper use of the fuel system. |
| 15101: Tank | |
| 15102: Line | |
| 15103: Line fitting | |
| 15104: Selector/valve | |
| 15105: Filter | |
| 15106: Strainer | |
| 15107: Screen | |
| 15108: Primer system | |
| 15109: Carburetor | |
| 15110: Pump | |
| 15111: Injector | |
| 15112: Vent | |
| 15113: Drain | |
| 15114: Cap | |
| 15115: Dump valve | |
| 15116: Ram air/induction air | |
| 15118: Nozzle | |
| 15119: Fuel control | |
| 15121: Fuel shutoff | |
| 15124: Electric boost pump | |
| 15125: Transfer pump | |
| 15127: Fuel flow divider/distributor | |
| 15128: Fuel quantity float/sensor | |
| 15131: PC line | |
| 15134: Low fuel warning light | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01022800XX: Fuel system (general) | I identified these codes by searching the coding manual for the phrase "fuel system" in the NTSB hierarchies.<br><br>Each of these codes represent the failure/contamination of a |
| 01022810XX: Fuel storage | |
| 01022820XX: Fuel distribution | |
| 01022821XX: Fuel-filter strainer | |
| 01022822XX: Fuel pumps | |
| 01022823XX: Fuel selector/shutoff valve | |
| 01022840XX: Fuel indication system | |
| 01022841XX: Fuel quantity indicator | |

| Fuel System Failure/Contamination | |
|---|---|
| This trigger represents the failure/contamination of the fuel system | |
| 01022841XX: Fuel quantity indicator | specific component in the fuel system.<br><br>Note that this trigger definition does not include the improper use of the fuel system. |
| 01022842XX: Fuel pressure | |
| 01022897XX: Fuel system wiring | |

Table 188: Lubricating System Failure/Contamination Trigger Definition

| **Lubricating System Failure/Contamination** | |
|---|---|
| This trigger represents the failure/contamination of the lubricating system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 15200: Lubricating system (general) | I identified these codes by searching the coding manual for the phrase “lubricating system” in the NTSB hierarchies.<br><br>Each of these codes represent the failure/contamination of a specific component in the lubrication system. |
| 15202: Oil line | |
| 15204: Oil pressure pump | |
| 15205: Oil scavenge pump | |
| 15206: Oil cooler | |
| 15208: Oil seal | |
| 15209: Oil gasket | |
| 15210: Oil regulator | |
| 15211: Oil tubing | |
| 15212: Oil filler cap | |
| 15213: Oil port/passage, internal | |
| 15214: Oil filter/screen | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 189: Engine Installation Failure Trigger Definition

| **Engine Installation Failure** | |
|---|---|
| This trigger represents the failure of the engine installation | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 15302: Engine installation—suspension mounts | I identified these codes by searching the coding manual for the phrase “engine installation” in the NTSB hierarchies. |
| 15303: Fire shield | |
| 15304: Mounting bolt | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 190: Improper Reading from/Failure of Engine Instruments Trigger Definition

| **Improper Reading from/Failure of Engine Instruments** | |
|---|---|
| This trigger represents the failure or improper readings from engine instruments | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 15400: Engine instruments (general) | I identified these codes by searching the coding manual |
| 15402: Tachometer | |

| Improper Reading from/Failure of Engine Instruments | |
|---|---|
| This trigger represents the failure or improper readings from engine instruments | |
| 15404: Fuel quantity gage | for the phrase "engine instrument" in the NTSB hierarchies.<br><br>Each of these codes represent the failure of an engine instrument. |
| 15405: Fuel flow gage | |
| 15410: Exhaust gas temperature | |
| 15412: Torquemeter | |
| 15413: Carburetor air temperature gage | |
| 15414: N1 (RPM) | |
| 15420: Engine RPM gage | |
| 15500: Torquemeter system AND ("failure-partial") | |
| 13002: Transmission oil pressure indicator AND ("no pressure") | |
| 13005: Dual tachometer AND ("false indication" OR "erratic" OR "failure-partial" | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057710XX: Engine indicating system—power indicating system | This code represent the failure of an engine instrument. |

Table 191: Reduction Gear Assembly Failure Trigger Definition

| **Reduction Gear Assembly Failure** | |
|---|---|
| This trigger represents the failure of the reduction gear assembly | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 15603: Reduction gear assembly—reduction gear | I identified these codes by searching the coding manual for the phrase "reduction gear" in the NTSB hierarchies.<br><br>Each of these codes represent the failure of a specific component in the reduction gear assembly. |
| 15606: accessory drive gear | |
| 15607: accessory drive bearing | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057210XX: Engine (turbine/turboprop)—reduction gear and shaft | This code represents the failure of a specific component in the reduction gear assembly. |

Table 192: Cooling System Failure Trigger Definition

| **Cooling System Failure** | |
|---|---|
| This trigger represents the failure of the cooling system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 15700: Cooling system (general) | I identified these codes by searching the coding manual for the phrase "cooling system" in the NTSB hierarchies.<br><br>Each of these codes represent the failure of a specific |
| 15701: Cowling | |
| 15707: Lines | |

| Cooling System Failure | |
|---|---|
| This trigger represents the failure of the cooling system | |
| | component in the cooling system. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 193: Turboshaft engine component Failure Trigger Definition

| **Turboshaft engine component Failure** | |
|---|---|
| This trigger represents the failure of turboshaft engine components | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 15900: Turboshaft engine (general) | I identified these codes by searching the coding manual for the phrase "turboshaft engine" in the NTSB hierarchies.<br><br>Each of these codes represent the failure of a specific component in the turboshaft engine. |
| 15901: Gas generator | |
| 15902: Gas generator turbine | |
| 15903: Combustion chamber | |
| 15904: Gas generator turbine shaft | |
| 15905: Free (power) turbine | |
| 15906: Fee turbine shaft | |
| 15907: Reduction gear box | |
| 15908: Power output shaft | |
| 15909: Free turbine governor | |
| 15910: Gas generator overspeed sensor/governor | |
| 15911: Free turbine overspeed sensor | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 194: Throttle/Power Control Failure Trigger Definition

| **Throttle/Power Control Failure** | |
|---|---|
| This trigger represents the failure of the throttle/power control | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 16000: Throttle/power lever (general) | I identified these codes by searching the coding manual for the word "throttle", "power", and "control" in the NTSB hierarchies.<br><br>Each of these codes represent the failure of a specific component in the throttle/power system.<br><br>Note that this trigger definition does not include the improper use of throttle/power control. |
| 16001: Push/pull rod | |
| 16002: Bellcrank | |
| 16004: Cable | |
| 16005: Linkage | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057600XX: Engine controls (general) | I identified these codes by searching the coding manual for the word "throttle", |
| 01057602XX: Mixture control | |
| 01057603XX: Power lever | |
| 01057697XX: Engine control system wiring | |

| Throttle/Power Control Failure | |
|---|---|
| This trigger represents the failure of the throttle/power control | |
| | "power", and "control" in the NTSB hierarchies.<br><br>Each of these codes represent the failure of a specific component in the throttle/power system.<br><br>Note that this trigger definition does not include the improper use of throttle/power control. |

Table 195: Carburetor Heat Control Failure Trigger Definition

| **Carburetor Heat Control Failure** | |
|---|---|
| This trigger represents the failure of the carburetor heat control | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 16400: Carburetor heat control (general) | I identified these codes by searching the coding manual for the word "carburetor" and "control" in the NTSB hierarchies.<br><br>Each of these codes represent the failure of a specific component in the carburetor heat control system.<br><br>Note that this trigger definition does not include the improper use of carburetor heat control |
| 16404: Cable/Push-pull rod | |
| 16405: Linkage | |
| 16407: Air box | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 196: Fuel Injection System Contamination/Failure Trigger Definition

| **Fuel Injection System Contamination/Failure** | |
|---|---|
| This trigger represents the failure of the fuel injection control system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 16600: Fuel injection control/system | I identified these codes by searching the coding manual for the phrase "fuel injection" in the NTSB hierarchies.<br><br>Each of these codes represent the failure of a specific component in the fuel injection system. |
| 16602: Bellcrank | |
| **NTSB Codes (post-2008)** | **Notes** |

| Fuel Injection System Contamination/Failure | |
|---|---|
| This trigger represents the failure of the fuel injection control system | |
| 01057313XX: Engine and fuel control-fuel injector nozzle | This code represents the failure of a specific component in the fuel injection system. |

Table 197: Induction Air System Contamination/Failure Trigger Definition

| **Induction Air System Contamination/Failure** | |
|---|---|
| This trigger represents the failure or contamination of the induction air system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 16700: Induction air control/system (general) | I identified these codes by searching the coding manual for the words "intake" and "induction" in the NTSB hierarchies.<br><br>Each of these codes represent the failure of a specific component in the induction air system. |
| 16709: Intake manifold | |
| 16711: Induction air ducting | |
| 16712: Engine inlet assembly | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057160XX: Powerplant-air intake | This code represents the failure of the air induction/intake system |
| 01057220XX: Air inlet section (core engine) | |

Table 198: Aircraft Light Not Available/Failure Trigger Definition

| **Aircraft Light Not Available/Failure** | |
|---|---|
| This trigger represents the unavailability or failure of aircraft lights | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17200: Light(s) | These codes represent the failure of aircraft lights.<br><br>Note that these codes do not include the ambient light or airport lighting. |
| 17202: Instrument light(s) | |
| 17206: Landing light(s) | |
| 17207: Exterior light(s) | |
| 17208: Annunciator panel light(s) | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 199: Improper use of Rotorcraft Flight Controls

| **Improper Use of Rotorcraft Flight Controls** | |
|---|---|
| This trigger represents the improper use of rotorcraft flight controls | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 10901: Rotorcraft flight control-cyclic control AND ("not safetied") | This code represents the improper use of rotorcraft flight controls |
| **NTSB Codes (post-2008)** | **Notes** |

| Improper Use of Rotorcraft Flight Controls | |
|---|---|
| This trigger represents the improper use of rotorcraft flight controls | |
| 01046700XX: Rotorcraft flight control (general) AND ("incorrect use/operation") | These codes represents the improper use of rotorcraft flight controls |
| 01046710XX: Rotorcraft flight control-Main rotor control AND ("unintentional use/operation") | |
| 01046720XX: Rotorcraft flight control-Tail rotor control AND ("incorrect use/operation") | |

Table 200: Pneumatic System Failure Trigger Definition

| **Pneumatic System Failure** | |
|---|---|
| This trigger represents the failure of the pneumatic system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 13103: Pneumatic system | This code represents the failure of the pneumatic system. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01023600XX: Pneumatic system (general) | I identified these codes by searching the coding manual for the words "pneumatic" in the NTSB hierarchies. |
| 01023610XX: Pneumatic distribution system | |
| 01023620XX: Pneumatic indicating system | |
| 01023697XX: Pneumatic system wiring | |

Table 201: Improper Use of Fuel System Trigger Definition

| **Improper Use of Fuel System** | |
|---|---|
| This trigger represents the improper use of the fuel system | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 22200: Fuel system (general) AND ("improper use of" OR "inadvertent deactivation" OR :disregarded") | These codes represent the improper use of the fuel system. |
| 22201: Fuel tank selector position AND ("improper" OR "insufficient information" OR "inadvertent" OR "inadvertent activation") | |
| 22202: Fuel boost pump selector position AND ("improper" OR "improper use of" OR "not selected") | |
| 22204: Fuel supply AND ("inadequate" OR "misjudged" OR "improper" OR "inattentive" OR "not maintained" OR "not identified" OR "misread" OR "inadvertent deactivation") | |
| 22205: Fuel management AND ("inaccurate" OR "improper" OR "inadequate") | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01022823XX: Fuel selector/shutoff valve AND ("unintentional use/operation") | This code represent the improper use of the fuel system. |

Table 202: Inadequate Facilities Provided by Organization Trigger Definition

| **Inadequate Facilities Provided by Organization** | |
|---|---|
| This trigger represents the inadequate facilities provided by the organization | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 70000: Facility inadequate (general) | |

| Inadequate Facilities Provided by Organization | |
|---|---|
| This trigger represents the inadequate facilities provided by the organization | |
| 70110: Inadequate design | The lack of facilities generally prevented the ground personnel, maintenance personnel, or builder from performing their tasks correctly—triggering the preflight mechanical issue state. |
| 70118: Inadequate external lighting | |
| 70122: Equipment interference | |
| **NTSB Codes (post-2008)** | **Notes** |
| 04022025XX: Resources-adequacy of equipment | The lack of facilities generally prevented the ground personnel, maintenance personnel, or builder from performing their tasks correctly—triggering the preflight mechanical issue state. |

Table 203: Improper Design and Development of Aircraft Trigger Definition

| Improper Design and Development of Aircraft | |
|---|---|
| This trigger represents the inadequate design of an aircraft | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 82000: Aircraft/equipment inadequate (general) | I identified these codes by searching the coding manual for the word “design” and “development”<br><br>The poor design triggers the preflight mechanical state. |
| 82100: Inadequate design | |
| 82110: Inadequate standards/requirements | |
| 82111: Inadequate instrument display | |
| 82114: Inadequate control location | |
| 82115: Inadequate control shape/size | |
| 82122: Equipment interference | |
| 82125: Inadequate handling/performance capabilities | |
| 82126: Inadequate airframe | |
| 82128: Inadequate aircraft component | |
| **NTSB Codes (post-2008)** | **Notes** |
| 04011010XX: Development-Design-equipment design | I identified these codes by searching the coding manual for the word “design” and “development”. The poor design triggers the preflight mechanical state. |
| 01012025XX: Selection/certification/testing-document information verification | |
| 04013000XX: Manufacture/production (general) | |
| 04013020XX: Document/information production | |

Table 204: Improper Use of Material Trigger Definition

| Use of Improper Material | |
|---|---|
| This trigger represents the inadequate design of an aircraft | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 84000: Material inadequate (general) | I identified these codes by searching the coding manual for the word “material”. |
| 84100: Material defect | |
| 84110: Inadequate quality control | |

| Use of Improper Material | |
|---|---|
| This trigger represents the inadequate design of an aircraft | |
| 84120: Material defect | The use of improper material triggers the preflight mechanical state. |
| 84200: Improper | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 205: Inadequate Oversight/Surveillance by Management/Regulator Trigger Definition

| Inadequate Oversight/Surveillance by Management/Regulator | |
|---|---|
| This trigger represents the lack of oversight by the management | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 90000: Inadequate surveillance of operations (general) | I identified these codes by searching the coding manual for the word “oversight” and “surveillance”. |
| 90100: Insufficient staff | |
| **NTSB Codes (post-2008)** | **Notes** |
| 04032000XX: Oversight (general) | I identified these codes by searching the coding manual for the word “oversight” and “surveillance”. |
| 04032010XX: Oversight of personnel | |
| 04032015XX: Oversight of operation | |
| 04032020XX: Oversight of maintenance | |
| 04032025XX: Equipment monitoring | |
| 04032035XX: Document/revision tracking | |
| 04032040XX: Oversight of regulation compliance | |

Table 206: Inadequate Pilot Training by Management Trigger Definition

| Inadequate Pilot Training by Management/Regulator | |
|---|---|
| This trigger represents the lack of oversight by the management | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 04030000XX: Support/oversight/monitoring (general) | I identified these codes by searching the coding manual for derivatives of the word “train”. I did not include the codes corresponding to lack of experience/training |
| 04031000XX: Training (general) | |
| 04031010XX: Inadequate initial training | |
| 04031020XX: Inadequate upgrade training | |
| 04031030XX: Emergency procedure training | |

Table 207: Insufficient Standards/Requirement Trigger Definition

| Insufficient Standards/Requirement | |
|---|---|
| This trigger represents the lack of oversight by the management | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 91000: Insufficient standards/requirements | I identified these codes by searching the coding manual |
| 91100: Insufficient standards/requirements-airman | |

| Insufficient Standards/Requirement | |
|---|---|
| This trigger represents the lack of oversight by the management | |
| 91200: Insufficient standards/requirements-aircraft | for the phrase “standards/requirements”. |
| 91300: Insufficient standards/requirements-operation/operator | |
| 91400: Insufficient standards/requirements-manufacturer | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 208: Inadequate Certification by Regulator Trigger Definition

| Inadequate Certification by Regulator | |
|---|---|
| This trigger represents the lack of oversight by the management | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 92000: Inadequate certification/approval (general) | I identified these codes by searching the coding manual for the words “certification” and “approval”. |
| 92100: Inadequate certification/approval -airman | |
| 92200: Inadequate certification/approval -aircraft | |
| 92300: Inadequate certification/approval –operation/operator | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 209: Inadequate Documentation/Record-Keeping Trigger Definition

| Inadequate Documentation/Record-Keeping | |
|---|---|
| This trigger represents the lack of record-keeping by the management | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 93000: Inadequate substantiation process | I identified these codes by searching the coding manual for the words “compliance”, “substantiation”, “records, and “documentation”.<br><br>These codes represent inadequate documentation by the management. |
| 93100: Inadequate compliance determination record-keeping | |
| 93200: Insufficient review (documentation) | |
| **NTSB Codes (post-2008)** | **Notes** |
| 04033000XX: Documentation/record keeping (general) | I identified these codes by searching the coding manual for the words “compliance”, “substantiation”, “records, and “documentation”.<br><br>These codes represent inadequate documentation by the management. |
| 02062500XX: Record keeping (general) | |
| 04033020XX: Testing records | |
| 04033025XX: Maintenance records | |

Table 210: Oil Contamination/Exhaustion Trigger Definition

| Oil Contamination/Exhaustion | |
|---|---|
| This trigger represents oil contamination or exhaustion | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Oil Contamination/Exhaustion | |
|---|---|
| This trigger represents oil contamination or exhaustion | |
| 17002: Fluids-oil | This code represents fluid exhaustion/contamination. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071020XX: Fluids/miscellaneous hardware-oil | This code represents fluid exhaustion/contamination. |

Table 211: Hydraulic Fluid Contamination/Exhaustion Trigger Definition

| Hydraulic Fluid Contamination/Exhaustion | |
|---|---|
| This trigger represents hydraulic fluid contamination or exhaustion | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17003: Fluids-hydraulic | This code represents fluid exhaustion/contamination. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071015XX: Fluids/miscellaneous hardware-hydraulic fluid | This code represents fluid exhaustion/contamination. |

Table 212: Contamination by Water Trigger Definition

| Contamination by Water | |
|---|---|
| This trigger represents water-contaminated fuel/oil | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17005: Fluids-water | This code represents fluid exhaustion/contamination. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 213: Insufficient Grease Trigger Definition

| Insufficient Grease | |
|---|---|
| This trigger represents water-contaminated fuel/oil | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17012: Fluids-Grease | This code represents fluid exhaustion/contamination. |
| **NTSB Codes (post-2008)** | **Notes** |
| 01071035XX: Fluids/miscellaneous hardware-grease | This code represents fluid exhaustion/contamination. |

Table 214: Improper Use of Carburetor Heat Trigger Definition

| Improper Use of Carburetor Heat | |
|---|---|
| This trigger represents the improper use of carburetor heat | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 22304: Carburetor heat AND (‘not used” OR “delayed” OR “improper use of “ OR “not deployed” OR “not selected” OR “unavailable”) | This code represents the improper use of carburetor heat control by the pilot. |

| Improper Use of Carburetor Heat | |
|---|---|
| This trigger represents the improper use of carburetor heat | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057231XX: Engine and fuel control—fuel control/carburetor AND (“not used/operated” OR “incorrect use/operation”) | This code represents the improper use of carburetor heat control by the pilot |

Table 215: Improper Weather Forecast Trigger Definition

| Improper Use of Weather Forecast | |
|---|---|
| This trigger represents an inaccurate/improper use of weather forecast | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24401: Weather forecast AND (“inaccurate” OR “not obtained” OR “disregarded”) | I identified this code by searching the coding manual for the word “forecast”. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 216: Improper Weather Observation Trigger Definition

| Improper Weather Observation | |
|---|---|
| This trigger represents improper observation of the weather | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24402: Weather observation AND (“not possible”) | This code indicates improper observation of the weather by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 217: Improper Use of Inflight Briefing Service Trigger Definition

| Improper Use of Inflight Briefing Service | |
|---|---|
| This trigger represents the improper use of briefs/information received during flight | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24406: Inflight briefing service AND (“not used”) | This code represents improper use of inflight briefing. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 218: Improper Use of Inflight Weather Advisories Trigger Definition

| Improper Use of Inflight Weather Advisories | |
|---|---|
| This trigger represents the improper use of weather advisories received during flight | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24407: Inflight weather advisories AND (“not obtained” OR “not followed”) | This code represents the improper use of inflight weather advisories. |
| **NTSB Codes (post-2008)** | **Notes** |

| Improper Use of Inflight Weather Advisories | |
|---|---|
| This trigger represents the improper use of weather advisories received during flight | |
| No code available | |

Table 219: Improper Aircraft Handling Trigger Definition

| **Improper Aircraft Handling** | |
|---|---|
| This trigger represents incorrect handling of the aircraft by the pilot | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24500: Aircraft handling AND (“poor” OR “not successful” OR “improper” OR “not maintained” OR “not possible” OR “abrupt” OR “inadequate” OR “not understood” OR “misjudged”) | This code represents improper handling of the aircraft by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 220: Improper Use of Cyclic Trigger Definition

| **Improper Use of Cyclic** | |
|---|---|
| This trigger represents incorrect use of the cyclic control by the pilot | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23201: Cyclic AND (“improper use of” OR “excessive” OR “improper” OR “restricted” OR “uncontrolled” OR “excessive” OR “not possible” OR “abrupt” OR “premature” OR “not understood” OR “delayed” OR ”inadvertent use” OR “inadvertent activation” OR “not available”) | This code represents improper use of cyclic control by the pilot.<br><br>This code is not the same as the one that is inferred in the absence of a trigger in certain accidents. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 221: Improper Use of Tail Rotor/Anti-Torque Control Trigger Definition

| **Improper Use of Tail Rotor/Anti-Torque Control** | |
|---|---|
| This trigger represents incorrect use of pedals to control the tail rotor | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23203: Tail rotor/anti-torque control AND (“improper use of” OR “excessive” OR “improper” OR “restricted” OR “uncontrolled” OR “excessive” OR “not possible” OR “abrupt” OR “not maintained” OR “premature” OR “not understood” OR “delayed” OR “inadvertent activation” OR “not available”) | This code represents improper use of anti-torque control by the pilot.<br><br>This code is not the same as the one that is inferred in the absence of a trigger in certain accidents. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 222: Improper Use of Control Friction Trigger Definition

| **Improper Use of Control Friction** | |
|---|---|
| This trigger represents incorrect use of control friction for the collective | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23205: Control friction AND (“not set” OR “improper use of” OR “inadvertent activation” OR “inadvertent” OR “diminished”) | This code represents the improper use of control friction by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 223: Improper Use of Wind Information Trigger Definition

| **Improper Use of Wind Information** | |
|---|---|
| This trigger represents situations where the pilot did not acquire or use the correct wind information | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24011: Wind information AND (“not followed” OR “disregarded” OR “misjudged” OR “misread” OR “not understood” OR “inaccurate” OR “not obtained”) | This code indicates improper use of wind information by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 224: Improper Fuel Calculation Trigger Definition

| **Improper Fuel Calculation** | |
|---|---|
| This trigger represents situations where the pilot did not correctly calculate the rate of fuel consumption during the mission | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24012: Fuel consumption calculation AND (“inaccurate” OR “inadequate” OR “improper” OR “not performed” OR “poor” OR “misjudged”) | This code represents improper fuel calculations by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 225: Assistance not Used/not Available Trigger Definition

| **Assistance not Used/not Available** | |
|---|---|
| This trigger represents situations where the pilot did not seek proper assistance or did not have access to assistance | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24009: Proper assistance AND (“not used” OR “not obtained” OR “not performed” OR “not available”) | This codes indicates that assistance was either unavailable or not used by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 226: Improper Understanding of performance Data Trigger Definition

| **Improper Understanding of performance Data** | |
|---|---|
| This trigger represents improper understanding and use of the aircraft's performance capabilities | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24019: Performance data AND ("not understood" OR "not followed" OR "misjudged" OR "disregarded" OR "exceeded" OR "inaccurate" OR "not complied with" OR "not followed" OR "not verified" OR "not obtained" OR "not identified") | This code indicates that the pilot failed to understand/disregarded the performance data. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 227: Improper Use of Emergency Light Trigger Definition

| **Improper Use of Emergency Light** | |
|---|---|
| This trigger represents incorrect use of emergency lights by the pilot | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23310: Emergency lights AND ("improper use of") | This code indicates the improper use of emergency lights by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 228: Improper Refueling Trigger Definition

| **Improper Refueling** | |
|---|---|
| This trigger represents improper refueling of the aircraft prior to flight | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24020: Refueling AND ("not performed" OR "delayed" OR "improper" OR "excessive" OR "not verified" OR "inadequate" OR "inattentive" OR "not performed" OR "not obtained") | This cod represents the improper refueling before flight. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 229: Improper Weather Evaluation Trigger Definition

| **Improper Weather Evaluation** | |
|---|---|
| This trigger represents improper evaluation of the weather conditions by the pilot before making a decision to fly | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24022: Weather evaluation AND ("improper" OR "inadequate" OR "poor" OR "misjudged" OR "inaccurate" OR "not received" OR "disregarded" OR "not verified") | This code represents improper weather evaluation by the pilot |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 230: Improper Use of Exterior/Navigation Lights Trigger Definition

| **Improper Use of Exterior/Navigation Lights** | |
|---|---|
| This trigger represents incorrect use of navigation lights by the pilot | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23314: Exterior/navigation lights AND ("not used") | This code represents the improper use of exterior/navigation lights. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 231: Delayed Flight to Alternate Destination Trigger Definition

| **Delayed Flight to Alternate Destination** | |
|---|---|
| This trigger represents a delayed decision by the pilot to fly to an alternate destination | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24025: Flight to alternate destination AND ("delayed") | This code indicates that the pilot delayed the decision to go to an alternate destination |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 232: Improper Ice/Frost Removal Trigger Definition

| **Improper Ice/Frost Removal** | |
|---|---|
| This trigger represents the failure to remove ice/defrost components before flight | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24004: Ice/frost removal from aircraft AND ("not removed" OR "not performed") | This code indicates that the pilot/ground crew failed to remove ice/frost before flight. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 233: Improper Compensation for Winds Trigger Definition

| **Improper Compensation for Winds** | |
|---|---|
| This trigger represents the pilot's improper compensation for winds during flight | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24026: Compensation for winds AND ("inadequate" OR "improper" OR "not performed" OR "misjudged" OR "disregarded" OR "not identified" OR "not maintained" OR "not performed" OR "not attained" OR "not obtained" OR "not understood" OR "inaccurate" OR "inattentive") | This code indicates that the pilot failed to compensate correctly for winds. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 234: Improperly Planned Approach Trigger Definition

| **Improperly Planned Approach** | |
|---|---|
| This trigger represents a poorly planned approach by the pilot | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24034: Planned approach AND ("improper" OR "poor" OR "inadequate" OR "misjudged" OR "inaccurate") | This code indicates an improperly planned approach by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 235: Engine Compartment Failure Trigger Definition

| **Engine Compartment Failure** | |
|---|---|
| This trigger represents the failure of the engine compartment | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 16903: Engine compartment AND ("fire" OR "not secured") | This code represents the failure of the engine compartment. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 236: Improper Use of Emergency Equipment Trigger Definition

| **Improper Use of Emergency Equipment** | |
|---|---|
| This trigger represents the improper use of emergency equipment | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23000: Emergency equipment AND ("not used" OR "delayed" OR "inadequate" OR "not deployed") | This code represents the improper use of emergency equipment. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 237: Improper Use of Emergency Floats Trigger Definition

| **Improper Use of Emergency Floats** | |
|---|---|
| This trigger represents the improper use of emergency floats | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23002: Emergency floats AND ("not deployed" OR "not activated") | This code indicates that the pilot failed to deploy the floats in a timely manner when executing a water landing. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 238: Improper Use of Fire Extinguisher Trigger Definition

| **Improper Use of Fire Extinguisher** | |
|---|---|
| This trigger represents the incorrect use of a fire extinguisher | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Improper Use of Fire Extinguisher | |
|---|---|
| This trigger represents the incorrect use of a fire extinguisher | |
| 22800: Fire extinguishing equipment AND ("not possible") | This code indicates the improper use of the fire extinguishing equipment. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 239: Engine Compressor Stall/Surge Trigger Definition

| **Engine Compressor Stall/Surge** | |
|---|---|
| This trigger represents the failure of the engine compartment | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 16911: Engine compressor stall/surge | This code represents a compressor stall. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 240: Engine Pre-Ignition/Detonation Trigger Definition

| **Engine Pre-Ignition/Detonation** | |
|---|---|
| This trigger represents engine pre-ignition/detonation | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 16912: Engine Pre-Ignition/Detonation | This code represents a pre-ignition/detonation in the engine. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 241: Uncontained Engine Failure Trigger Definition

| **Uncontained Engine Failure** | |
|---|---|
| This trigger represents uncontained engine failure | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 16913: Uncontained engine failure | This code represents the uncontained failure of the engine. |
| **NTSB Codes (post-2008)** | **Notes** |
| 343: Uncontained engine failure | This code represents the uncontained failure of the engine. |

Table 242: Improper Use/Failure of Furnishing Trigger Definition

| **Improper Use/Failure of Furnishing** | |
|---|---|
| This trigger represents the improper use/failure of furnishings | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Improper Use/Failure of Furnishing | |
|---|---|
| This trigger represents the improper use/failure of furnishings | |
| 17100: Miscellaneous-equipment/furnishing | This code represents the failure of on-board furnishing. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 243: Entanglement of Cargo Restraints Trigger Definition

| Entanglement of Cargo Restraints | |
|---|---|
| This trigger represents the entanglement of cargo restraints | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17102: Miscellaneous-cargo restraints AND (“entangled”) | This code represents the entanglement of cargo restraints. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 244: Improper Use/Failure of Rafts Trigger Definition

| Improper Use/Failure of Rafts | |
|---|---|
| This trigger represents the improper use/failure of rafts | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17107: Miscellaneous-rafts | This code indicates the improper use/failure of life raft after water landing. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 245: Improper Use/Failure of Seat Belts Trigger Definition

| Improper Use/Failure of Seat Belts | |
|---|---|
| This trigger represents the improper use/failure of seat belts | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17110: Miscellaneous-seat belt | This code represents the improper use/failure of the seat belt. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 246: Improper Use/Failure of Shoulder Harness Trigger Definition

| Improper Use/Failure of Shoulder Harness | |
|---|---|
| This trigger represents the improper use/failure of shoulder harness | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17111: Miscellaneous-shoulder harness | This code indicates failure/improper use of the shoulder harness. |

| Improper Use/Failure of Shoulder Harness | |
|---|---|
| This trigger represents the improper use/failure of shoulder harness | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 247: Improper Use of Engine Inlet Covers Trigger Definition

| Improper Use of Engine Inlet Covers | |
|---|---|
| This trigger represents the improper use of engine inlet covers | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17119: Miscellaneous-engine inlet covers | This code indicates improper use of engine inlet covering. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 248: Entanglement of Helmet Trigger Definition

| Entanglement of Helmet | |
|---|---|
| This trigger represents the entanglement of the helmet | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17120: Miscellaneous-helmet AND ("entangled") | This code suggest helmet entanglement. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 249: Entanglement of Helmet Trigger Definition

| Not Possible | |
|---|---|
| This trigger represents situations where the NTBS used the "not possible" modifier to indicate that the pilot could not have executed a particular action. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 3131: Not possible (modifier) | The NTSB used this modifier to indicate that the pilot could not have possibly carried out a particular action. For example, they used this code with subject codes for aircraft control and rotor RPM. Both cases suggest that the pilots found it "impossible" to maintain control or RPM. |
| **NTSB Codes (post-2008)** | **Notes** |
| 021: Not possible (modifier) | The NTSB used this modifier to indicate that the pilot could not have possibly carried out a particular action. For example, they used this code with subject codes for aircraft control and rotor RPM. Both cases suggest that the pilots |

| **Not Possible** | |
|---|---|
| This trigger represents situations where the NTBS used the "not possible" modifier to indicate that the pilot could not have executed a particular action. | |
| | found it "impossible" to maintain control or RPM. |

Table 250: Incorrect Use of Throttle and/or Collective Input Trigger Definition

| **Improper Use of Throttle and/or Collective Input** | |
|---|---|
| This trigger represents improper throttle setting and/or collective input that triggers an improper RPM hazardous state. | |
| **User-defined Code** | **Notes** |
| I defined this trigger by combining two other triggers:<br>• Improper use of throttle/powerplant controls<br>• Improper use of collective | This trigger is inferred only if a trigger is not available from the accident report.<br><br>This trigger is used when helicopter engine is operational, and when there is no mechanical issue with the collective control. |

Table 251: Incorrect Use of Collective and/or Cyclic Trigger Definition

| **Improper Use of Collective and/or Cyclic** | |
|---|---|
| This trigger improper use of the collective or cyclic that can trigger an improper autorotation or inflight loss of control. | |
| **User-defined Code** | **Notes** |
| I defined this trigger by combining two other triggers:<br>• Improper use of collective<br>• Improper use of cyclic | This trigger is inferred only if a trigger is not available from the accident report.<br><br>This trigger can cause the system to transition to an inflight loss of control state.<br><br>It can also trigger an improper autorotation after a loss of engine power (or during simulated autorotation). |

Table 252: Impossible/reduced control authority after system failure Trigger Definition

| **Impossible/reduced control after system failure** | |
|---|---|
| This trigger represents the situations where the pilot has limited or no control over the aircraft after the failure of critical flight control components | |
| **User-defined Code** | **Notes** |

| Impossible/reduced control after system failure | |
|---|---|
| I defined this trigger by:<br>• System failure state appears before inflight loss of control | System failure is associated with several accidents (including those that involved inflight loss of control). Failure of critical flight control components (e.g., cyclic) afford the pilot reduced control authority over the aircraft (if not impossible to control).<br><br>I inferred this trigger if: the NTSB did not use the "not possible" modifier, and the accident involved an inflight loss of control after a system failure.<br><br>I capture this situation by defining the "Impossible/reduced control authority after system failure" trigger. |

Table 253: No/Failed Recovery Action from Uncontrolled Descent Trigger Definition

| No/Failed Recovery Action from Uncontrolled Descent | |
|---|---|
| This trigger represents no action/failed attempt by the pilot to recover from an inflight loss of control, and triggers an end state. | |
| **User-defined Code** | **Notes** |
| I defined this trigger by combining two other triggers:<br>• Lack of action by the pilot<br>• Improper remedial action by the pilot | Many accident reports do not specify the types of pilot action that causes (triggers) the system to move from an inflight loss of control state to an end state.<br><br>For completeness, I defined the "No/failed recovery action from uncontrolled descent" trigger.<br><br>This trigger is inferred when the NTSB accident report does not mention any remedial action by the pilot to recover from the inflight loss of control state. |

Table 254: Improper Load Jettison Trigger Definition

| **Improper Load Jettison** | |
|---|---|
| This trigger represents an improper jettison of external load by the pilot. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24540: Load jettison | This code represents incorrect or delayed jettison of external load/attachment by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 255: Improper Remedial Action Trigger Definition

| **Improper Remedial Action** | |
|---|---|
| This trigger represents an improper corrective action by the pilot. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24542: Remedial action | This trigger, as the name suggests, represents incorrect/insufficient remedial action by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| 060: Attempted remedial action | This trigger, as the name suggests, represents incorrect/insufficient remedial action by the pilot. |

Table 256: Improper Pull-up Trigger Definition

| **Improper Pull-up** | |
|---|---|
| This trigger represents an improper pull-up by the pilot. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24547: Pull-up | This trigger suggests incorrect pull-up action by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 257: Improper Recovery from Bounced Landing Trigger Definition

| **Improper Recovery from Bounced Landing** | |
|---|---|
| This trigger represents an improper recovery from a bounced landing. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24562: Recovery from bounced landing | This trigger represents the inability of the pilot to recover from a bounced landing. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 258: Improper Touch-and-go Trigger Definition

| **Improper Touch-and-go** | |
|---|---|
| This trigger represents an improper touch-and-go. | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Improper Touch-and-go | |
|---|---|
| This trigger represents an improper touch-and-go. | |
| 24563: Touch-and-go | This trigger indicates that the pilot did not perform a proper touch-and-go maneuver. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 259: Improper Use of/Inadequate Flight Advisories Trigger Definition

| Improper Use of/Inadequate Flight Advisories | |
|---|---|
| This trigger represents improper use or inadequate flight advisories. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24605: Flight advisories | This trigger indicates that the pilot failed to follow advisories during flight. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 260: Improper Use of/Inadequate ARTCC Service Trigger Definition

| Improper Use of/Inadequate ARTCC Service | |
|---|---|
| This trigger represents improper use of or inadequate ARTCC service. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24606: ARTCC service | This trigger indicates that pilot did not use/receive sufficient information from the ARTCC service. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 261: Improper Use of/Inadequate Traffic Advisory Trigger Definition

| Improper Use of/Inadequate Traffic Advisory | |
|---|---|
| This trigger represents improper use or inadequate traffic advisory. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24612: Traffic advisory | This trigger indicates that the pilot did not use/receive proper traffic information. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 262: Improper Use of/Inadequate Safety Advisory Trigger Definition

| Improper Use of/Inadequate Safety Advisory | |
|---|---|
| This trigger represents improper use or inadequate traffic advisory. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24615: safety advisory | This trigger indicates that the pilot did not use/receive proper safety advisory. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 263: Improper Use of/Inadequate Radar Assistance to VFR Aircraft Trigger Definition

| **Improper Use of/Inadequate Radar Assistance to VFR Aircraft** | |
|---|---|
| This trigger represents improper use of/inadequate radar assistance to VFR aircraft. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24616: Radar assistance to VFR aircraft | This trigger indicates that the pilot did not use/receive proper radar assistance. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 264: Improper Use of/Inadequate Assistance from Flight Service Station Trigger Definition

| **Improper Use of/Inadequate Assistance from Flight Service Station** | |
|---|---|
| This trigger represents improper use of/inadequate assistance from flight service station. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24613: Flight service station (FSS) service | This trigger indicates that the pilot did not use/receive proper FSS service. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 265: Improper Use of Inflight Weather Information Trigger Definition

| **Improper Use of Inflight Weather Information** | |
|---|---|
| This trigger represents improper use of inflight weather information. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24620: Improper inflight weather information | This trigger indicates that the pilot did not properly use the inflight weather information. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 266: Improper Crew Coordination Trigger Definition

| **Improper Crew Coordination** | |
|---|---|
| This trigger represents improper crew coordination. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24624: Crew/group coordination | This trigger indicates that the crew did not coordinate properly. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 267: Improper Crew/Passenger Briefing Trigger Definition

| **Improper Crew/Passenger Briefing** | |
|---|---|
| This trigger represents improper crew or passenger briefing. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24625: Crew/group briefing | |

| **Improper Crew/Passenger Briefing** | |
|---|---|
| This trigger represents improper crew or passenger briefing. | |
| 24626: Passenger briefing | I identified these codes by searching for the word “briefing”. I excluded weather briefings. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 268: Not Recognizing Hazardous Condition Trigger Definition

| **Not Recognizing Hazardous Condition** | |
|---|---|
| This trigger represents the crew not recognizing or heeding a hazardous condition/warning. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24628: Unsafe hazardous condition | The NTSB used these generic codes to suggest that the pilot failed to recognize (and act) on hazardous condition warnings. |
| 24629: Unsafe/hazardous condition warning | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 269: Disturbance Trigger Definition

| **Disturbance** | |
|---|---|
| This trigger represents a disturbance/disruptive event for the crew/pilot. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24701: Disturbance | Trigger indicates disturbance by another crew member or passenger. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 270: Control Interference Trigger Definition

| **Control Interference** | |
|---|---|
| This trigger represents control interference during flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24705: Control interference | This trigger indicates the pilot experienced some form of interference with the aircraft flight controls. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 271: Relinquishing Control Trigger Definition

| **Relinquishing Control** | |
|---|---|
| This trigger represents relinquishing control of the aircraft. | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Relinquishing Control | |
|---|---|
| This trigger represents relinquishing control of the aircraft. | |
| 24706: Relinquishing control | This trigger indicates that the pilot relinquished control of the aircraft improperly. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 272: Suicide Trigger Definition

| Suicide | |
|---|---|
| This trigger represents suicide by the pilot or passenger. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24707: Suicide | Trigger indicates suicide by occupant/pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 273: Improper Security Trigger Definition

| Improper Security | |
|---|---|
| This trigger represents improper security of the aircraft. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24711: Security | Trigger indicates lack of security. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 274: Sabotage Trigger Definition

| Sabotage | |
|---|---|
| This trigger represents sabotage before or during flight. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24710: Sabotage | Trigger indicates intentional tampering with the system to cause harm. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 275: Improper Rescue/Evacuation Trigger Definition

| Improper Rescue/Evacuation | |
|---|---|
| This trigger represents improper rescue and evacuation. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24712: Evacuation | The NTSB used the codes to indicate improper evacuation or rescue of occupants after an accident. |
| 24714: Rescue | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 276: Encounter with Jet/Propeller Blast Trigger Definition

| **Encounter with Jet/Propeller Blast** | |
|---|---|
| This trigger represents improper rescue and evacuation. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24718: Propeller/jet blast encounter | Trigger indicates that a crew member/passenger encountered the rotor blades. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 277: Mast Bumping Trigger Definition

| **Mast Bumping** | |
|---|---|
| This trigger represents mast bumping. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24806: Mast bumping | Trigger indicates that the main rotor made contact with the fuselage of the aircraft. Generally occurs during blade divergence. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 278: Engine Tearaway Trigger Definition

| **Engine Tearaway** | |
|---|---|
| This trigger represents engine tearaway. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 355: Engine tearaway | This trigger indicates that separation of the engine from the aircraft fuselage. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 279: Fire Warning System Failure Trigger Definition

| **Fire Warning System Failure** | |
|---|---|
| This trigger represents the failure of the fire warning system. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 12400: Fire warning system | Trigger indicates failure of the warning system. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 280: Oxygen System Failure Trigger Definition

| **Oxygen System Failure** | |
|---|---|
| This trigger represents the failure of the oxygen system. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 12500: Oxygen system | Trigger indicates failure of the oxygen system. |
| **NTSB Codes (post-2008)** | **Notes** |

| **Oxygen System Failure** | |
|---|---|
| This trigger represents the failure of the oxygen system. | |
| No code available | |

Table 281: Improper Use of Cabin Heater Trigger Definition

| **Improper Use of Cabin Heater** | |
|---|---|
| This trigger represents the improper use of cabin heater. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 12910: Cabin heater AND (“not activated”) | Trigger indicates improper use of cabin heating. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 282: Fire Extinguisher Failure Trigger Definition

| **Fire Extinguisher Failure** | |
|---|---|
| This trigger represents the failure of the fire extinguisher. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 12606: Fire extinguisher—portable AND (“exhaustion” OR “improper” OR “inadequate”) | Trigger indicates failure of the fire extinguisher. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 283: Fire Extinguisher Failure Trigger Definition

| **Air conditioning System Failure** | |
|---|---|
| This trigger represents the failure of the air conditioning system. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 12901: Air conditioning/heating/pressurization | Trigger indicates failure of AC system. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 284: Tail Boom Failure Trigger Definition

| **Tail boom Failure** | |
|---|---|
| This trigger represents the failure of the tail boom. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 13007: Miscellaneous rotorcraft—Tail boom | Trigger indicates tailboom failure |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 285: Tail Cone Failure Trigger Definition

| **Tail Cone Failure** | |
|---|---|
| This trigger represents the failure of the tail cone. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 13009: Miscellaneous rotorcraft—Tail cone | Trigger indicates failure of the tail cone. |
| **NTSB Codes (post-2008)** | **Notes** |

| Tail Cone Failure | |
|---|---|
| This trigger represents the failure of the tail cone. | |
| No code available | |

Table 286: Tail Pylon Failure Trigger Definition

| Tail Pylon Failure | |
|---|---|
| This trigger represents the failure of the tail pylon. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 13008: Miscellaneous rotorcraft—Tail pylon | Trigger indicates failure of tail pylon |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 287: Improper Use/Failure of Emergency Floatation Gear Trigger Definition

| Improper Use of Floatation Gear | |
|---|---|
| This trigger represents the improper use of floatation gear. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 13006: Miscellaneous rotorcraft—floatation gear | Trigger indicates failure/improper use of emergency floatation gear. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 288: Improper Use of Chip Detector System Trigger Definition

| Improper Use of Chip Detector System | |
|---|---|
| This trigger represents the improper use of chip detector system. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 13010: Miscellaneous rotorcraft—chip detector system—gear box | Trigger indicates improper use of chip detector system. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 289: Transmission Tube Failure Trigger Definition

| Transmission Tube Failure | |
|---|---|
| This trigger represents the failure of the transmission tube. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 13014: Miscellaneous rotorcraft—transmission support tube/attachment | Trigger indicates failure of the transmission tube. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 290: Pitot-Static System Failure Trigger Definition

| Pitot-static System Failure | |
|---|---|
| This trigger represents the failure of the pitot-static system. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 13101: Pitot/Static system | Trigger indicates failure of the pitot/static system. |

| Pitot-static System Failure | |
|---|---|
| This trigger represents the failure of the pitot-static system. | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 291: Improper Use of Flight Controls Trigger Definition

| Improper Use of Flight Controls | |
|---|---|
| This trigger represents the improper use of flight controls. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 22100: Flight controls AND (“improper use of” OR “improper” OR “restricted” OR not possible” OR “not received”) | Trigger indicates improper use of flight controls. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 292: Pitot-Static System Failure Trigger Definition

| Improper Use of Trim Setting | |
|---|---|
| This trigger represents the improper use of trim setting by the pilot. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 22120: Trim setting | Trigger indicates improper use of the trim setting by the pilot. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 293: Improper Use of Unspecified Fluid Trigger Definition

| Improper Use of Unspecified Fluid | |
|---|---|
| This trigger represents the improper use of unspecified fluid. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17000: Fluid | The NTSB used the general “fluid” code to suggest some form of contamination/improperly used fluid. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 294: Unspecified Engine Component Failure Trigger Definition

| Unspecified Engine Component Failure | |
|---|---|
| This trigger represents the failure of an unspecified engine component. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 16900: Miscellaneous | These codes indicate that an engine component failed. The NTSB codes do not always specify the component that failed. |
| 16910: Miscellaneous—engine | |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 295: Improper Use of the Parachute/Drag Chute Trigger Definition

| **Improper Use of Parachute/Drag Chute** | |
|---|---|
| This trigger represents the improper use of the drag chute | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 17115: Miscellaneous equipment/furnishing—parachute/drag chute | This trigger indicates the improper use of the parachute. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 296: Improper Use of the Auxiliary Power Unit (APU) Trigger Definition

| **Improper Use of the Auxiliary Power Unit (APU)** | |
|---|---|
| This trigger represents the improper use of the auxiliary power unit. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23303: Auxiliary power unit (APU) | This trigger indicates the improper use of the APU. Generally, this subject code is associated with failing to remove APU tubes before departure (in helicopter operations). |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 297: Improper/Inadequate Radar Altimeter Trigger Definition

| **Improper/Inadequate Radar Altimeter** | |
|---|---|
| This trigger represents the improper use of the auxiliary power unit. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 23102: Radar altimeter AND ("poor") | This trigger indicates a malfunctioning altimeter |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 298: Not Identifying Crosswind Component Trigger Definition

| **Not Identifying Crosswind Component** | |
|---|---|
| This trigger represents the pilot's failure to recognize the crosswind component during flight | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24579: Crosswind component AND ("not identified") | This trigger indicates the pilot's failure to recognize (and correct for) the crosswind component during flight |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 299: Disregarding Minimum Descent Altitude Trigger Definition

| **Disregarding Minimum Descent Altitude** | |
|---|---|
| This trigger represents the pilots disregard for the minimum descent altitude. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| 24529: Minimum descent altitude | This trigger indicates that the pilot disregarded the minimum descent altitude. |
| **NTSB Codes (post-2008)** | **Notes** |
| No code available | |

Table 300: Tailstrike Trigger Definition

| **Tailstrike** | |
|---|---|
| This trigger represents the tail striking an object or terrain. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | This trigger indicates that the tail struck an object/terrain (generally the ground during an improper flare). |
| **NTSB Codes (post-2008)** | **Notes** |
| 091: Tailstrike | This trigger indicates that the tail struck an object/terrain (generally the ground during an improper flare). |

Table 301: Oil System Failure Definition

| **Oil System Failure** | |
|---|---|
| This trigger represents the failure of the oil system. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 01057261XX: Oil system | This trigger indicates the failure of the oil system. |

Table 302: Incorrect Action Selection Definition

| **Incorrect Action Selection** | |
|---|---|
| This trigger represents an incorrect choice made by the pilot to perform a particular action. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02041010XX: Action—incorrect action selection | This trigger is not informative. It only suggests that he pilot “did something wrong”. |

Table 303: Incorrect Sequence of Actions Definition

| **Incorrect Sequence of Action** | |
|---|---|
| This trigger represents an incorrect sequence of actions taken by the pilot/maintenance personnel. | |
| **NTSB Codes (pre-2008)** | **Notes** |

| Incorrect Sequence of Action | |
|---|---|
| This trigger represents an incorrect sequence of actions taken by the pilot/maintenance personnel. | |
| 80400: Conditions/step(s)—improper sequence | This trigger indicates that the pilot performed an incorrect sequence of actions. |
| **NTSB Codes (post-2008)** | **Notes** |
| 02041010XX: Action—incorrect action sequence | This trigger indicates that the pilot performed an incorrect sequence of actions. |

Table 304: Delayed Action Definition

| Delayed Action | |
|---|---|
| This trigger represents delayed action by the pilot. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | Note that in the pre-2008 system, the NTSB indicated delayed action as a modifier. This modified was associated with subject codes. For example, “Collective—delayed” would be a subject-modifier combination. |
| **NTSB Codes (post-2008)** | **Notes** |
| 02041025XX: Action—delayed action | The NTSB had a separate subject code for the nature of action taken by the pilot. It no longer uses “delayed” as a modifier. |

Table 305: Lack of Action Definition

| Lack of Action | |
|---|---|
| This trigger represents delayed action by the pilot/maintenance personnel. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | Note that in the pre-2008 system, the NTSB did not explicitly point out a “lack of” action. They used the “lack of” modifier with multiple subject codes (e.g., fuel, collective control). |
| **NTSB Codes (post-2008)** | **Notes** |
| 02041030XX: Action—lack of action | The NTSB had a separate subject code for the nature of action taken by the pilot. It no longer uses “lack of” as a modifier. |

Table 306: Forgotten Action/Omission Definition

| **Forgotten Action/Omission** | |
|---|---|
| This trigger represents a missed/forgotten action by the pilot/maintenance personnel. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | The NTSB did not use a subject code specify forgotten/omitted actions in the pre-2008 system |
| **NTSB Codes (post-2008)** | **Notes** |
| 02041035XX: Action—forgotten action/omission | The NTSB had a separate subject code to indicate forgotten or omitted actions. |

Table 307: Incomplete Action Definition

| **Incomplete Action** | |
|---|---|
| This trigger represents an action that the pilot/maintenance personnel failed to complete. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02041040XX: Action—incomplete action | The NTSB had a separate subject code to indicate incomplete actions. |

Table 308: Unnecessary Action Definition

| **Unnecessary Action** | |
|---|---|
| This trigger represents an action that the pilot/maintenance personnel failed to complete. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| No code available | |
| **NTSB Codes (post-2008)** | **Notes** |
| 02041040XX: Action—unnecessary action | The NTSB had a separate subject code to indicate unnecessary actions. |

# APPENDIX C. SEQUENCING OF HAZARDOUS STATES

Table 309: Sequencing Rules for Disoriented/Lacking Awareness State

| **Disoriented/lacking Awareness State** | |
|---|---|
| Hazardous state where the pilot fails to maintain the correct altitude/clearance from terrain or objects. | |
| **States that can appear immediately after are** | **Notes** |
| Lack of visual lookout/distracted | After becoming disoriented, pilots were generally not able to maintain visual reference.<br><br>In some accidents, the pilots failed to monitor key flight parameters (e.g., airspeed, RPM). |
| Improper airspeed | |
| Improper RPM | |
| Improper altitude/clearance | |
| Improper descent | |
| Inflight loss of control | |

Table 310: Sequencing Rules for Improper Climb State

| **Improper Climb State** | |
|---|---|
| Hazardous state where the aircraft's climb was incorrect/climb capability was exceeded/climb rate was incorrect. | |
| **States that can appear immediately after are** | **Notes** |
| Improper altitude/clearance | Failure to maintain proper climb can result in descent and improper altitude/clearance.<br><br>In many accidents, pilots failed to recognize that they were in a hazardous climb state, and failed to take appropriate remedial actions that triggered other hazardous states such as improper airspeed, improper RPM, and inflight loss of control. |
| Improper descent | |
| Improper airspeed | |
| Improper rotor RPM | |
| Inflight loss of control | |
| On-ground loss of control | |

Table 311: Sequencing Rules for Improper Distance State

| **Improper Distance State** | |
|---|---|
| Hazardous state where the distance from the runway/helipad/landing site is incorrect. | |
| **States that can appear immediately after are** | **Notes** |
| Improper flare | After aircraft entered an improper distance state, pilots tried to take corrective measures by flaring excessively, or were unable to level-off in time. |
| Improper level-off | |
| On-ground loss of control | |

Table 312: Sequencing Rules for Improper Descent State

| **Improper Descent State** | |
|---|---|
| Hazardous state where the aircraft's descent was incorrect/descent rate was incorrect. | |
| **States that can appear immediately after are** | **Notes** |
| Improper altitude/clearance | In many accidents that did not involve vortex ring state or clipping object/terrain, the positions of improper altitude/clearance and improper descent are interchangeable.<br><br>If the accident sequence involves the loss of engine power state, then the improper descent follows. |
| Improper airspeed | |
| Vortex ring state | |
| Improper RPM | |
| Loss of tail rotor effectiveness | |
| Inflight loss of control | |
| Improper flare | |
| Improper level-off | |

Table 313: Sequencing Rules for Intentional/Inadvertent flight through poor weather state

| **Intentional/Inadvertent flight through poor weather state** | |
|---|---|
| Hazardous state where the pilot intentionally or inadvertently flew into poor weather conditions. | |
| **States that can appear immediately after are** | **Notes** |
| Disoriented/lacking awareness | After intentional/inadvertent flight through poor weather states, pilots generally were disoriented and unable to maintain visual reference.<br><br>In some accidents, pilots exceeded the helicopter's hover performance capabilities after flight through poor weather.<br><br>In certain accidents, the subsequent state could have been as a result of the impact of poor weather on the aircraft (e.g., system failure, loss of engine power). |
| Lack of visual lookout/distracted | |
| Exceeding helicopter hover performance | |
| Improper altitude/clearance | |
| Improper descent | |
| Improper airspeed | |
| Improper RPM | |
| Vortex ring state | |
| System failure | |
| Loss of engine power | |
| Improper autorotation | |
| Loss of tail rotor effectiveness | |
| Aircraft stall/spin state | |
| Inflight loss of control | |
| Improper flare | |

Table 314: Sequencing Rules for Prevailing/Existing weather state

| **Prevailing/Existing weather and light state** | |
|---|---|
| Hazardous weather state that existed during the flight. | |
| **States that can appear immediately after are** | **Notes** |
| Improper vertical takeoff | After flight through prevailing weather and light states, pilots generally were disoriented and unable to maintain visual reference. |
| Disoriented/lacking awareness | |
| Lack of visual lookout/distracted | |
| Exceeding helicopter hover performance | |
| Improper altitude/clearance | |
| Improper descent | |
| Improper airspeed | |

| Prevailing/Existing weather and light state | |
|---|---|
| Improper RPM | In some accidents, pilots exceeded the helicopter's hover performance capabilities after flight through poor weather.<br><br>In certain accidents, the subsequent state could have been as a result of the impact of poor weather on the aircraft (e.g., system failure, loss of engine power). |
| Vortex ring state | |
| System failure | |
| Loss of engine power | |
| Improper autorotation | |
| Loss of tail rotor effectiveness | |
| Aircraft stall/spin state | |
| Inflight loss of control | |
| Improper flare | |

Table 315: Sequencing Rules for Improper Altitude/Clearance State

| **Improper Altitude/Clearance State** | |
|---|---|
| Hazardous state where the pilot fails to maintain the correct altitude/clearance from terrain or objects. | |
| **States that can appear immediately after are** | **Notes** |
| Midair collision | In many accidents, pilots failed to maintain altitude, followed by the loss of airspeed or RPM.<br><br>Subsequently, the aircraft enters the LOC state.<br><br>Generally, if an accident did not involve LOC, but cited improper RPM improper airspeed, the: improper airspeed or improper RPM can appear before improper altitude/clearance. |
| Improper descent | |
| Exceeding aircraft yaw performance | |
| Improper airspeed | |
| Improper RPM | |
| Aircraft stall/spin state | |
| Inflight loss of control | |
| Improper flare | |

Table 316: Sequencing Rules for Wake Turbulence state

| **Wake turbulence State** | |
|---|---|
| Hazardous state where the aircraft flew through the wake vortices of another aircraft. | |
| **States that can appear immediately after are** | **Notes** |
| Loss of engine power | In some accidents, the aircraft engine "flamed out" after flying through wake turbulence. |
| Inflight loss of control | Flight through wake turbulence resulted in the pilot losing control of the aircraft. In the post-2008 system, the NTSB introduced the "inflight upset" code, which I use to trigger the system from the wake turbulence state, and into the LOC state. |

Table 317: Sequencing Rules for Exceeding Aircraft Yaw Performance State

| **Exceeding Aircraft Yaw Performance State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design yaw performance capabilities. | |
| **States that can appear immediately after are** | **Notes** |
| Loss of engine power | In one accident, the aircraft entered a state where it was operating its design yaw capabilities. When in this state, an engine component failed, triggering a loss of engine power state.<br><br>In many accidents, pilots failed to recognize the exceeding yaw performance state, and subsequently failed to maintain airspeed, rotor RPM.<br><br>As mentioned in the rules for airspeed and RPM, failure to maintain either of these parameters resulted in LTE or LOC. |
| Improper airspeed | |
| Improper RPM | |
| Loss of tail rotor effectiveness (LTE) | |
| Inflight loss of control | |

Table 318: Sequencing Rules for Improper Turn/Bank state

| **Improper Turn/Bank State** | |
|---|---|
| Hazardous state where the aircraft exceeds its banking/roll performance during flight. | |
| **States that can appear immediately after are** | **Notes** |
| Improper altitude/clearance | Similar to the improper climb states, not executing a proper turn can be followed by an improper descent and/or loss of altitude.<br><br>Not correcting for an improper turn can results in a loss of airspeed and decay in rotor RPM.<br><br>As mentioned in the rules for airspeed and RPM, failure to maintain either of these parameters resulted in LTE or LOC. |
| Improper descent | |
| Improper airspeed | |
| Loss of tail rotor effectiveness (LTE) | |
| Inflight loss of control | |

Table 319: Sequencing Rules for Loss of Tail Rotor Effectiveness State

| **Loss of Tail Rotor Effectiveness State** | |
|---|---|
| Hazardous state where the helicopter tail rotor does not provide the requisite thrust to maintain directional control. | |
| **States that can appear immediately after are** | **Notes** |
| Inflight loss of control | In many accidents that involved loss of tail rotor |

| Loss of Tail Rotor Effectiveness State | |
|---|---|
| | effectiveness, the pilot was unable to recover the aircraft and subsequently lost control. |

Table 320: Sequencing Rules for Loss of Engine Power State

| **Loss of Engine Power State** | |
|---|---|
| Hazardous state where an aircraft's engine is not operational. | |
| **States that can appear immediately after are** | **Notes** |
| Improper autorotation | In accidents that involved loss of engine power, improper autorotations generally followed.<br><br>If the codes do not suggest an improper autorotation, then any of the states (that compose the key elements of an improper autorotation) can follow.<br><br>A combination of improper descent and airspeed can result in a vortex ring state.<br><br>As mentioned in the rules for airspeed and RPM, failure to maintain either of these parameters resulted in LTE or LOC. |
| Exceeding Aircraft Engine-out Capability | |
| Improper altitude/clearance | |
| Improper descent | |
| Improper airspeed | |
| Improper RPM | |
| Hazardous height-velocity regime | |
| Vortex ring state | |
| Loss of tail rotor effectiveness (LTE) | |
| Aircraft stall/spin state | |
| Inflight loss of control | |
| Improper flare | |

Table 321: Sequencing Rules for System Failure State

| **System Failure State** | |
|---|---|
| Hazardous state where an aircraft's system(s)/component(s) have failed/malfunctioned. | |
| **States that can appear immediately after are** | **Notes** |
| Improper autorotation | In accidents that involved system failure, improper autorotations generally followed.<br><br>If the codes do not suggest an improper autorotation, then any of the states (that compose the key elements of an improper autorotation) can follow.<br><br>Note that in the case of many system failure accidents, the pilots are not able to maintain flight parameters (e.g., RPM, airspeed). These accidents |
| Improper altitude/clearance | |
| Improper descent | |
| Improper airspeed | |
| Vortex ring state | |
| Improper RPM | |
| Loss of tail rotor effectiveness (LTE) | |
| Aircraft stall/spin state | |
| Inflight loss of control | |
| Improper flare | |

| System Failure State | |
|---|---|
| | generally have the "not possible" trigger.<br><br>In many accidents where the LOC state followed system failure, pilots were not able to control the aircraft. |

Table 322: Sequencing Rules for Improper Autorotation State

| Improper Autorotation | |
|---|---|
| Hazardous state where the pilot failed to execute a safe autorotative landing. | |
| **States that can appear immediately after are** | **Notes** |
| Vortex ring state | If the aircraft enters an improper autorotation state, then the hazardous states that can follow are: vortex ring state, loss of tail rotor effectiveness, stall/spin, or inflight loss of control.<br><br>Note that, generally, LOC followed improper autorotation if an accident involved loss of engine power or system failure. |
| Loss of tail rotor effectiveness (LTE) | |
| Aircraft stall/spin state | |
| Inflight loss of control | |

Table 323: Sequencing Rules for Aircraft Stall/Spin State

| Aircraft Stall/Spin State | |
|---|---|
| Hazardous state where the lifting surfaces of an aircraft (i.e., wings or rotor blades) exceed a critical angle of attack they experience a loss of lift, and enter a stalled state. | |
| **States that can appear immediately after are** | **Notes** |
| Inflight loss of control | After the blade/aircraft stall or spin, the aircraft enters the inflight loss of control state. |

Table 324: Sequencing Rules for Lack of Visual Lookout/Distracted State

| Lack of Visual Lookout/Distracted State | |
|---|---|
| Hazardous state where the pilot failed to maintain visual lookout for terrain/other aircraft or was distracted. | |
| **States that can appear immediately after are** | **Notes** |
| Improper altitude/clearance | A pilot in this state generally failed to maintain clearance from objects/terrain or failed to monitor key flight parameters.<br><br>In some cases, the NTSB used this code to describe the distracted nature of |
| Improper descent | |
| Midair collision | |
| Low fuel state | |
| Improper airspeed | |
| Improper RPM | |
| Inflight loss of control | |
| On-ground loss of control | |

| Lack of Visual Lookout/Distracted State | |
|---|---|
| Improper distance | maintenance personnel. The state-based approach uses the information code for the "personnel" associated with this state. |

Table 325: Sequencing Rules for Low Fuel State

| Low Fuel State | |
|---|---|
| Hazardous state where the aircraft was operating with low fuel level. | |
| **States that can appear immediately after are** | **Notes** |
| Loss of engine power | After the aircraft entered the low fuel state, it generally experienced a fuel exhaustion, triggering a loss of engine power.<br><br>In one accident, the low fuel state promoted the pilot to make an incorrect decision and fly into IMC conditions. |
| Intentional/inadvertent flight through poor weather | |

Table 326: Sequencing Rules for Low Oil State

| Low Oil State | |
|---|---|
| Hazardous state where the aircraft was operating with low oil level. | |
| **States that can appear immediately after are** | **Notes** |
| Loss of engine power | After the low oil state, the oil starvation/exhaustion can trigger a loss of engine power.<br><br>In some cases, depending on the nature of oil (e.g., transmission oil), the system transitioned to the system failure state. |
| System failure | |

Table 327: Sequencing Rules for Low Hydraulic Fluid State

| Low Hydraulic Fluid State | |
|---|---|
| Hazardous state where the aircraft was operating with low hydraulic fluid level. | |
| **States that can appear immediately after are** | **Notes** |
| System failure | After the low hydraulic fluid state, the system transitioned to the system failure state. |

Table 328: Sequencing Rules for Improper Height-Velocity Regime State

| **Improper Height-Velocity Regime State** | |
|---|---|
| Hazardous state where the aircraft is operating in the unsafe region of the "Deadman's curve". | |
| **States that can appear immediately after are** | **Notes** |
| Improper altitude/clearance | This hazardous indicates that the system was operating in hazardous region of the height-velocity curve.<br><br>This state is part of the definition for the improper autorotation state.<br><br>If the accident codes do not mention 24520: Autorotation, then the improper height-velocity curve state can appear by itself in an accident. |
| Improper descent | |
| Improper airspeed | |
| Improper RPM | |
| Loss of tail rotor effectiveness (LTE) | |
| Inflight loss of control | |

Table 329: Sequencing Rules for Improper Heading State

| **Improper Heading State** | |
|---|---|
| Hazardous state where the pilot failed to maintain heading/course. | |
| **States that can appear immediately after are** | **Notes** |
| Inflight loss of control | After entering the improper heading state, and failing to correct improper heading can trigger an inflight loss of control. |

Table 330: Sequencing Rules for Improper Lift-off State

| **Improper Lift-off State** | |
|---|---|
| Hazardous state where the aircraft did not lift-off correctly. | |
| **States that can appear immediately after are** | **Notes** |
| Exceeding aircraft takeoff capability | In helicopter accidents, an improper lift-off was immediately followed by exceeding takeoff capability, or inflight loss of control.<br><br>In some situations, improper lift-off resulted in loss of control when on the ground. |
| Inflight loss of control | |
| On-ground loss of control | |

Table 331: Sequencing Rules for Improper Operation of Rotorcraft State

| **Improper Operation of Rotorcraft State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design performance capabilities. | |
| **States that can appear immediately after are** | **Notes** |
| Improper turn | This hazardous state translates from the generic "operation of rotorcraft" code in the NTSB coding manual.<br><br>In helicopter accidents, this state was followed by improper turn, loss of engine power, or system failure state. |
| Loss of engine power | |
| System failure | |

Table 332: Sequencing Rules for On-ground Poor Weather

| **On-ground Poor Weather State** | |
|---|---|
| Hazardous state where the pilot failed to maintain heading/course. | |
| **States that can appear immediately after are** | **Notes** |
| Inflight loss of control | The aircraft encountered poor weather during takeoff and subsequently lost control. |

Table 333: Sequencing Rules for Improper Run-on Landing State

| **Improper Run-on Landing State** | |
|---|---|
| Hazardous state where the aircraft did not transition correctly from forward flight to landing. | |
| **States that can appear immediately after are** | **Notes** |
| This state is always followed by an end state | |

Table 334: Sequencing Rules for Improper Vertical Takeoff State

| **Improper Vertical Takeoff State** | |
|---|---|
| Hazardous state where the pilot did not perform a correct vertical takeoff. | |
| **States that can appear immediately after are** | **Notes** |
| Lack of visual lookout/distracted | After an improper vertical takeoff, pilots failed to maintain visual look out for objects.<br><br>Failing to maintain lookout (and take corrective action) transitioned the system to the improper altitude/clearance state.<br><br>In some accidents, pilots failed to correct the improper vertical takeoff and transitioned to an |
| Improper altitude/clearance | |
| Improper airspeed | |
| Improper RPM | |
| Vortex ring state (VRS) | |

| Improper Vertical Takeoff State | |
|---|---|
| | improper airspeed or improper RPM state. |

Table 335: Sequencing Rules for Improper Go-around State

| **Improper Go-around State** | |
|---|---|
| Hazardous state where the pilot did not perform a correct go-around. | |
| **States that can appear immediately after are** | **Notes** |
| Improper descent | Pilots perform a go-around to abort an approach into an airport/landing site.<br><br>After an improper go-around, in many accidents, pilots were not able to arrest the descent.<br><br>In some accidents, pilots failed to maintain airspeed, or rotor RPM. Failing to maintain these flight parameters subsequently resulted in LOC. |
| Improper airspeed | |
| Improper RPM | |
| Inflight loss of control | |

Table 336: Sequencing Rules for Exceeding Design Stress Limits State

| **Exceeding Design Stress Limits State** | |
|---|---|
| Hazardous state where aerodynamic loads on the aircraft exceed the design stress limits. | |
| **States that can appear immediately after are** | **Notes** |
| Loss of engine power | When pilots operated aircraft outside the design stress range, it generally resulted in a loss of engine power or system failure. |
| System failure | |

Table 337: Sequencing Rules for Improper Translational Lift State

| **Improper Translational Lift State** | |
|---|---|
| Hazardous state where the aircraft did not transition correctly from hover to forward flight. | |
| **States that can appear immediately after are** | **Notes** |
| Improper airspeed | Translational lift state happens when the helicopter transitions from vertical flight to forward flight.<br><br>A Federal Aviation Advisory Circular states that "loss of translational lift results in increased power demand" and "while operating near maximum power demand, the increased power demand could |
| Improper RPM | |
| Vortex ring state | |
| Loss of tail rotor effectiveness | |
| Inflight loss of control | |

| Improper Translational Lift State | |
|---|---|
| | result in decreased rotor RPM" (NTSB ID: CHI00LA132).<br><br>In many accidents, pilots failed to maintain rotor RPM or airspeed after not attaining proper translational lift. |

Table 338: Sequencing Rules for Exceeding Helicopter Hover Performance State

| **Exceeding Helicopter Hover Performance State** | |
|---|---|
| Hazardous state where the aircraft exceeds its design hover performance. | |
| **States that can appear immediately after are** | **Notes** |
| Improper altitude/clearance | When a helicopter is operated in excess of its hover performance capabilities, generally, it experiences a loss of altitude and begins to descend.<br><br>After exceeding hover performance, pilots are generally not able to maintain translational lift. |
| Improper descent | |
| Improper translational lift | |
| Improper airspeed | |
| Vortex ring state | |
| Improper RPM | |
| Inflight loss of control | |
| On-ground loss of control | |

Table 339: Sequencing Rules for Exceeding Aircraft Takeoff Capability State

| **Exceeding Aircraft Takeoff Performance State** | |
|---|---|
| Hazardous state where the aircraft exceeds its design takeoff performance. | |
| **States that can appear immediately after are** | **Notes** |
| Loss of engine power | When a helicopter exceeds its takeoff performance, it can result in an improper takeoff.<br><br>In some cases, after exceeding takeoff performance, the aircraft experienced a loss of engine power, failed to maintain RPM, or improper autorotation.<br><br>In some accidents, if the aircraft took-off after exceeding takeoff performance, the pilots lost control. |
| Improper vertical takeoff | |
| Improper RPM | |
| Improper autorotation | |
| Inflight loss of control | |

Table 340: Sequencing Rules for Exceeding Aircraft Landing Capability State

| **Exceeding Aircraft Landing Performance State** | |
|---|---|
| Hazardous state where the aircraft exceeds its design landing performance. | |
| **States that can appear immediately after are** | **Notes** |
| Exceeding design stress limits | After exceeding the landing performance, the aircraft can enter the state where it was being operated beyond its stress limits.<br><br>In some cases, the NTSB codes indicated that the helicopter entered a ground resonance state, which was generally followed by a system failure.<br><br>In some accidents, the pilot lost control of the aircraft after the landing performance had deteriorated (the report indicated that helicopter had flown into the rotor wash of a larger helicopter—not captured in the codes) |
| Ground resonance | |
| System failure | |
| Inflight loss of control | |

Table 341: Sequencing Rules for Exceeding Aircraft Performance Limits State

| **Exceeding Aircraft Performance Limits State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design performance capabilities. | |
| **States that can appear immediately after are** | **Notes** |
| Improper descent | This state is obtained from the generic NTSB code “17300: Aircraft performance (general)”. Generally, after this state, the aircraft can experience a loss of altitude or improper descent.<br><br>In some cases, the pilots were not able to fly in the prevailing weather conditions, failed to maintain requisite RPM, airspeed, or subsequently lost control. |
| Improper altitude/clearance | |
| System failure | |
| Improper airspeed | |
| Improper rotor RPM | |
| Inflight loss of control | |

Table 342: Sequencing Rules for Improper Operation of Rotorcraft State

| **Improper Operation of Rotorcraft State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design performance capabilities. | |
| **States that can appear immediately after are** | **Notes** |
| Improper turn/bank | This state is obtained from the generic NTSB code “24800: |
| System failure | |

| Improper Operation of Rotorcraft State | |
|---|---|
| | Rotorcraft operations". The NTSB used this code to indicate that the "rotorcraft was not operated correctly".<br><br>From accident data, the states that can follow are, improper turn/bank or a system failure state. |

Table 343: Sequencing Rules for Exceeding Aircraft Yaw Performance State

| **Exceeding Aircraft Yaw Performance State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design yaw performance capabilities. | |
| **States that can appear immediately after are** | **Notes** |
| Exceeding design stress limits | Exceeding yawing performance frequently in inflight loss of control. |
| System failure | |
| Improper airspeed | |
| Improper RPM | |
| Inflight loss of control | |

Table 344: Sequencing Rules for Exceeding Aircraft Engine-out Capability State

| **Exceeding Aircraft Engine-out Capability State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its performance capabilities after the loss of engine power. | |
| **States that can appear immediately after are** | **Notes** |
| Improper autorotation | This state usually appears in multi-engine aircraft.<br><br>This state can appear after a loss of engine power state, and is used to indicate exceeding performance limits with one engine inoperative. |

Table 345: Sequencing Rules for Exceeding Aircraft Crosswind Capability State

| **Exceeding Aircraft Crosswind Performance State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design crosswind performance capabilities. | |
| **States that can appear immediately after are** | **Notes** |
| Exceeding design stress limits | If the pilot failed to recognize that the aircraft was being operated beyond its crosswind performance limits, the system could transition to an improper airspeed, improper RPM, or eventually an inflight loss of control. |
| Inflight loss of control | |

Table 346: Sequencing Rules for Exceeding Aircraft Configuration Capability State

| **Exceeding Aircraft Configuration Capability State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design capabilities for a given configuration. | |
| **States that can appear immediately after are** | **Notes** |
| In accidents, this state is always followed by an end state. | |

Table 347: Sequencing Rules for Wheels-up Landing State

| **Wheels-up Landing State** | |
|---|---|
| Hazardous state where the pilot performs a landing without extending the landing gear. | |
| **States that can appear immediately after are** | **Notes** |
| In accidents, this state is always followed by an end state. | |

Table 348: Sequencing Rules for Exceeding Slope Limitation State

| **Exceeding Slope Limitation State** | |
|---|---|
| Hazardous state where the pilot operated the aircraft beyond its design capability in inclined/sloped terrain. | |
| **States that can appear immediately after are** | **Notes** |
| On-ground loss of control | After entering the state where the helicopter had exceeded its slope limitations, the aircraft either experienced an on-ground loss of control or transitioned to an end state. |

Table 349: Sequencing Rules for Runway Overshoot State

| **Runway Overshoot State** | |
|---|---|
| Hazardous state where the aircraft departed the runway surface during takeoff or landing. | |
| **States that can appear immediately after are** | **Notes** |
| In accidents, this state is always followed by an end state. | |

Table 350: Sequencing Rules for Improper Power-on Landing State

| **Improper Power-on Landing State** | |
|---|---|
| Hazardous state where the pilot performs an improper landing with engine(s) operational. | |
| **States that can appear immediately after are** | **Notes** |
| Improper flare | Improper flare or failure to level-off correctly can appear after the pilot performs an incorrect power-on landing. The NTSB used the power-on landing code similar to the run-on landing/precautionary landing code. |
| Improper level-off | |

Table 351: Sequencing Rules for Runway Undershoot State

| **Runway Undershoot State** | |
|---|---|
| Hazardous state where the aircraft landed short of the runway. | |
| **States that can appear immediately after are** | **Notes** |
| In accidents, this state is always followed by an end state. | |

Table 352: Sequencing Rules for Runway Incursion State

| **Runway Incursion State** | |
|---|---|
| Hazardous state where the aircraft entered runway incorrectly/without clearance | |
| **States that can appear immediately after are** | **Notes** |
| In accidents, this state is always followed by an end state. | |

Table 353: Sequencing Rules for On-ground Loss of Control State

| **On-ground Loss of Control State** | |
|---|---|
| Hazardous state where the pilot fails to maintain control of aircraft heading and attitude when on the ground. | |
| **States that can appear immediately after are** | **Notes** |
| In accidents, this state is always followed by an end state. | |

Table 354: Sequencing Rules for Improper Level-off State

| **Improper Level-off State** | |
|---|---|
| Hazardous state where the pilot fails to bring the helicopter to a level attitude (usually in preparation for a landing). | |
| **States that can appear immediately after are** | **Notes** |
| In accidents, this state is always followed by an end state. | |

Table 355: Sequencing Rules for Low Coolant State

| **Low Coolant State** | |
|---|---|
| Hazardous state where the aircraft was operating with low coolant level. | |
| **States that can appear immediately after are** | **Notes** |
| System failure | After entering a low coolant state, the system can enter a loss of engine power state or system failure state. Generally, the failure occurs due to overheating. |
| Loss of engine power | |

Table 356: Sequencing Rules for Low Grease State

| **Low Grease State** | |
|---|---|
| Hazardous state where the aircraft was operating with low grease level. | |
| **States that can appear immediately after are** | **Notes** |
| System failure | In some accidents, engine or system components fail during the low grease state, transitioning the system to a |
| Loss of engine power | |

| Low Grease State | |
|---|---|
| | system failure or loss of engine power state. |

Table 357: Sequencing Rules for Improper Precautionary Landing State

| Improper Precautionary Landing State | |
|---|---|
| Hazardous state where the pilot did not execute a proper precautionary landing. | |
| **States that can appear immediately after are** | **Notes** |
| Improper airspeed | These states can appear after an improper precautionary landing.<br><br>In some accidents, the pilot failed to execute a proper precautionary landing, which was followed by an improper flare.<br><br>The positions of RPM and/or airspeed can be interchanged with the position of the improper precautionary landing state (in accidents where failure to maintain RPM or airspeed resulted in an improper precautionary landing state) |
| Improper rotor RPM | |
| Improper flare | |

Table 358: Sequencing Rules for Hazardous Powerplant Operation State

| Hazardous Powerplant Operation State | |
|---|---|
| Hazardous state where the aircraft powerplant parameters are in excess of the specified operational limits. | |
| **States that can appear immediately after are** | **Notes** |
| Loss of engine power | This code translates from the NTSB subject code that suggests operation of aircraft powerplant beyond its capabilities. |
| System failure | |

# APPENDIX D. RULES LINKING HAZARDOUS STATES AND TRIGGERS

Table 359: Triggers into the Intentional/Inadvertent Flight through Poor Weather State

| **Intentional/Inadvertent Flight through Poor Weather State** | |
|---|---|
| Hazardous state where the pilot intentionally or inadvertently flew into poor weather conditions | |
| **Triggers into this state are** | **Notes** |
| Improper inflight planning/decision-making | These triggers cause the system to enter the intentional/inadvertent flight into poor weather state.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper weather evaluation | |
| Improper use of procedures/directives | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Unnecessary action | |

Table 360: Triggers into the Disoriented/Lacking Awareness State

| **Disoriented/Lacking Awareness State** | |
|---|---|
| Hazardous state where the pilot is lost, disoriented, unable to maintain visual reference/perception | |
| **Triggers into this state are** | **Notes** |
| Time spent in poor weather | In many cases, the system transitions to a disoriented state by virtue of the time spent in poor weather. I use a time-bounded trigger to represent the system moving into the disoriented state. |

Table 361: Triggers into the Improper RPM State

| **Improper RPM State** | |
|---|---|
| Hazardous state where the main rotor RPM is either too low (or too high) | |
| **Triggers into this state are** | **Notes** |
| Improper use of collective | Improper use of collective can trigger an improper RPM state.<br><br>Improper use of throttle/powerplant controls triggers improper RPM only when the engine is operational.<br><br>In some cases, the pilot failed put in the requisite cyclic control to maintain rotor RPM. Note that in accidents involving the LOC state, this trigger can |
| Improper Use of Throttle/Powerplant Controls | |
| Improper use of cyclic | |
| Improper remedial action | |
| Improper use of flight controls | |
| Improper use of rotorcraft flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |

| Improper RPM State | |
|---|---|
| Hazardous state where the main rotor RPM is either too low (or too high) | |
| Not possible | cause the system to enter the LOC state as well.<br><br>The NTSB used generic codes that translated to improper use of rotorcraft flight controls and improper use of flight control.<br><br>• Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power<br>• No action after disoriented state can be inferred if the preceding state was "disoriented/lacking awareness".<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of throttle and/or collective input | |
| Improper use of collective and/or cyclic | |
| No action after disoriented state | |

Table 362: Triggers into the Improper Autorotation State

| Improper Autorotation State | |
|---|---|
| Hazardous state where the pilot failed to maintain key flight parameters like rotor RPM, descent, airspeed, altitude, or flare during autorotation. | |
| **Triggers into this state are** | **Notes** |
| Improper use of collective | Improper use of collective can trigger an improper autorotation where the pilot failed to maintain rotor RPM.<br><br>In some cases, the pilot failed put in the requisite cyclic control to maintain heading, descent angle/rate, rotor RPM.<br><br>Note that in accidents involving the LOC state, this trigger can cause the system to enter the LOC state as well. |
| Improper use of cyclic | |
| Improper remedial action | |
| Improper use of flight controls | |
| Improper use of rotorcraft flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of collective and/or cyclic | |

| **Improper Autorotation State** | |
|---|---|
| Hazardous state where the pilot failed to maintain key flight parameters like rotor RPM, descent, airspeed, altitude, or flare during autorotation. | |
| Improper use of collective (during simulated autorotation) | The NTSB used generic codes that translated to improper use of rotorcraft flight controls and improper use of flight control.<br><br>• Improper use of collective (during simulated autorotation) can be inferred as long as there was no loss of engine power and the accident sequence began with a simulated autorotation.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br>• No action after disoriented state can be inferred if the preceding state was "disoriented/lacking awareness".<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| No action after disoriented state | |

Table 363: Triggers into the Vortex Ring State

| **Vortex Ring State** | |
|---|---|
| Hazardous state where a rapidly descending helicopter's main rotor blades are engulfed by a doughnut-shaped vortex, resulting in a loss of lift. | |
| **Triggers into this state are** | **Notes** |
| Improper use of cyclic | Improper use of the cyclic can cause an unusual attitude for helicopter, which may be conducive for vortex ring state. Improper use of the throttle can result in airspeed that is conducive to the vortex ring state.<br><br>Improper use of collective can affect the RPM (which, along with other parameters) triggering a vortex ring state. |
| Improper Use of Throttle/Powerplant Controls | |
| Improper use of collective | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |

| Vortex Ring State | |
|---|---|
| Hazardous state where a rapidly descending helicopter's main rotor blades are engulfed by a doughnut-shaped vortex, resulting in a loss of lift. | |
| Improper use of collective and/or cyclic | The NTSB used generic codes that translated to improper use of rotorcraft flight controls and improper use of flight control.<br><br>• Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br>• No action after disoriented state can be inferred if the preceding state was "disoriented/lacking awareness".<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of throttle and/or collective input | |
| No action after disoriented state | |

Table 364: Triggers into the Improper Altitude/Clearance State

| Improper Altitude/Clearance State | |
|---|---|
| Hazardous state where the aircraft is operating too close to the ground, terrain, water, or object. | |
| **Triggers into this state are** | **Notes** |
| Improper use of cyclic | • Improper use of the cyclic can cause an unusual attitude for helicopter, which can trigger a loss of altitude/clearance.<br>• Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br>• No action after disoriented state can |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of throttle and/or collective input | |
| Improper use of collective and/or cyclic | |
| No action after disoriented state | |

| Improper Altitude/Clearance State | |
|---|---|
| | be inferred if the preceding state was "disoriented/lacking awareness".<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |

Table 365: Triggers into the Improper Climb State

| Improper Climb State | |
|---|---|
| Hazardous state where the aircraft's climb was incorrect/climb capability was exceeded/climb rate was incorrect. | |
| **Triggers into this state are** | **Notes** |
| Improper use of cyclic | To execute a proper climb, pilots need to lower the collective, control the cyclic to maintain attitude, and maintain appropriate throttle setting.<br><br>• Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of collective | |
| Improper Use of Throttle/Powerplant Controls | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of collective and/or cyclic | |
| Improper use of throttle and/or collective input | |

Table 366: Triggers into the Improper Distance State

| Improper Distance State | |
|---|---|
| Hazardous state where the distance from the runway/helipad/landing site is incorrect. | |
| **Triggers into this state are** | **Notes** |

| Improper Distance State | |
|---|---|
| Improper use of cyclic | In order to maintain proper distance from the landing site, pilots need to coordinate cyclic, collective, and throttle input. Failure to use any one of them correctly can trigger this hazardous state.<br><br>• Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br>• No action after disoriented state can be inferred if the preceding state was "disoriented/lacking awareness".<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of collective | |
| Improper Use of Throttle/Powerplant Controls | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of collective and/or cyclic | |
| Improper use of Throttle and/or Collective Input | |
| No action after disoriented state | |

Table 367: Triggers into the Improper Heading State

| Improper Heading State | |
|---|---|
| Hazardous state where the pilot failed to maintain heading/course. | |
| **Triggers into this state are** | **Notes** |
| Improper use of cyclic | In order to maintain correct heading or course, pilots need to use collective control or use the anti-torque pedals.<br><br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br>• No action after disoriented state can be inferred if the preceding state was |
| Improper use tail rotor/anti-torque control | |
| Improper compensation for winds | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Improper use of collective and/or cyclic | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |

| Improper Heading State | |
|---|---|
| Improper use of collective and/or cyclic | "disoriented/lacking awareness". <br>• Improper use of anti-torque control can be inferred when the improper heading state is preceded by LTE or exceeding crosswind component states.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| No action after disoriented state | |
| Improper use of anti-torque control | |

Table 368: Triggers into the Improper Airspeed State

| Improper Airspeed State | |
|---|---|
| Hazardous state where the aircraft airspeed is either too low (or too high). | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | Choosing the correct throttle setting, and cyclic control input are key to maintaining airspeed during forward flight.<br><br>• Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of cyclic | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of throttle and/or collective input | |
| Improper use of collective and/or cyclic | |
| No action after disoriented state | |

Table 369: Triggers into the Improper Descent State

| Improper Descent State | |
|---|---|
| Hazardous state where the aircraft's descent was incorrect/descent rate was incorrect. | |
| **Triggers into this state are** | **Notes** |
| Improper use of collective | |

| **Improper Descent State** | |
|---|---|
| Improper use of throttle/powerplant controls | In a normal descent, a helicopter loses altitude at a controlled rate in a controlled attitude (FAA. 2016).<br><br>To execute a proper a descent, the pilot should lower the collective to maintain RPM, cyclic control for airspeed, and anti-torque pedals to maintain attitude. Not performing any of these actions correctly can trigger an improper descent.<br><br>• Improper use of collective and/or cyclic can be inferred irrespective of the state of the engine.<br>• If the accident did not involve a loss of engine power or improper RPM state (but involved improper descent), then I inferred the improper use of anti-torque control.<br>• No action after disoriented state can be inferred if the preceding state was “disoriented/lacking awareness”.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of tail rotor/anti-torque | |
| Improper maneuvering | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use collective and/or cyclic | |
| No action after disoriented state | |
| Improper use of anti-torque control | |

Table 370: Triggers into the Wake Turbulence state

| **Wake turbulence State** | |
|---|---|
| Hazardous state where the aircraft flew through the wake vortices of another aircraft. | |
| **Triggers into this state are** | **Notes** |
| Improper inflight planning/decision-making | This state occurred when the helicopter flew into the wake of a preceding aircraft. |
| Improper maneuvering | |
| Improper remedial action | |
| Incorrect action selected | |
| Incorrect action performed | |

| Wake turbulence State | |
|---|---|
| Incorrect sequence of actions | Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |

Table 371: Triggers into the Improper Turn/Bank state

| **Improper Turn/Bank State** | |
|---|---|
| Hazardous state where the aircraft exceeds its banking/roll performance during flight. | |
| **Triggers into this state are** | **Notes** |
| Improper use of cyclic | Amount of bank depends on cyclic input<br>Proper use of anti-torque essential during turn.<br><br>Both, improper use of collective and/or cyclic, and improper anti-torque control could be inferred. Preference is given to anti-torque control if the accident involved LTE.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of tail rotor/anti-torque control | |
| Improper compensation for winds | |
| Improper maneuvering | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use collective and/or cyclic | |
| Improper use of anti-torque control | |

Table 372: Triggers into the Runway Overshoot State

| **Runway Overshoot State** | |
|---|---|
| Hazardous state where the aircraft departed the runway surface during takeoff or landing. | |
| **Triggers into this state are** | **Notes** |
| Improper planned approach | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power. |
| Improper use of cyclic | |
| Improper use of throttle/powerplant controls | |
| Improper maneuvering | |
| Improper use of throttle and/or collective input | |
| Improper use collective and/or cyclic | |

Table 373: Triggers into the Aircraft Stall/Spin State

| **Aircraft Stall/Spin State** |
|---|
| Hazardous state where the lifting surfaces of an aircraft (i.e., wings or rotor blades) exceed a critical angle of attack they experience a loss of lift, and enter a stalled state. |

| Aircraft Stall/Spin State | |
|---|---|
| **Triggers into this state are** | **Notes** |
| Improper use of collective | Improper RPM is one of main reasons for blade stall. Excessive rotor RPM decay can stall all rotor blades and render the helicopter uncontrollable. The pilot can control the RPM by collective pitch control, proper use of powerplant controls (when the engine is operational).<br>• Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of throttle/powerplant controls | |
| Improper use of cyclic | |
| Improper use of deicing system | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Improper use of throttle and/or collective input | |
| Improper use collective and/or cyclic | |

Table 374: Triggers into the Lack of Visual Lookout/Distracted State

| Lack of Visual Lookout/Distracted State | |
|---|---|
| Hazardous state where the pilot failed to maintain visual lookout for terrain/other aircraft or was distracted. | |
| **Triggers into this state are** | **Notes** |
| Disturbance | • Time spent in poor weather state can trigger lack of visual lookout/distracted state only if the accident did not mention disoriented state.<br>• No action after disoriented state can be inferred if the preceding state was “disoriented/lacking awareness”. |
| Not possible | |
| Time spent in poor weather state | |
| No action after disoriented state | |

Table 375: Triggers into the Exceeding Slope Limitation State

| Exceeding Slope Limitation State | |
|---|---|
| Hazardous state where the pilot operated the aircraft beyond its design capability in inclined/sloped terrain. | |
| **Triggers into this state are** | **Notes** |
| Choosing unsuitable terrain for takeoff/landing | The pilot must exercise extreme caution when landing/taking off from inclined surfaces.<br><br>Exceeding the slope limitation (without appropriate corrective action) can transition the system to a rollover end state.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of cyclic | |
| Improper use of collective | |
| Improper touchdown | |
| Improper inflight planning/decision-making | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use collective and/or cyclic | |

Table 376: Triggers into the Improper Aircraft Weight and Balance State

| Improper Aircraft Weight and Balance State | |
|---|---|
| Hazardous state where the aircraft's balance is affected due to improper loading or shifting of the center of gravity. | |
| **Triggers into this state are** | **Notes** |
| Improper load jettison | In some accidents, the pilots failed to/improperly jettison the load.<br><br>In some cases, improper preflight planning, or improper loading of cargo triggered this hazardous state. |
| Improper cargo loading/tie-down | |
| Improper preflight planning | |

Table 377: Triggers into the Wheels-up Landing State

| Wheels-up Landing State | |
|---|---|
| Hazardous state where the pilot performs a landing without extending the landing gear. | |
| **Triggers into this state are** | **Notes** |
| Gear not extended | The pilot's failure to extend the gear before landing or improper use of the landing gear can trigger a wheels-up landing.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of landing gear | |
| Improper inflight planning/decision-making | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |

Table 378: Triggers into the Improper Run-on Landing State

| **Improper Run-on Landing State** | |
|---|---|
| Hazardous state where the aircraft did not transition correctly from forward flight to landing. | |
| **Triggers into this state are** | **Notes** |
| Improper use of cyclic | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br>• No/failed remedial action after LOC can be inferred if LOC was the preceding state.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of collective | |
| Improper use of throttle/powerplant controls | |
| Improper inflight planning/decision-making | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of throttle and/or collective input | |
| Improper use collective and/or cyclic | |
| No/failed remedial action after LOC | |

Table 379: Triggers into the Low Fuel State

| **Low Fuel State** | |
|---|---|
| Hazardous state where the aircraft was operating with low fuel level. | |
| **Triggers into this state are** | **Notes** |
| Improper use of powerplant controls | These triggers can cause the system to enter a low-fuel state. Note that a fuel system failure (e.g., fuel leak) will trigger a system failure state.<br><br>The improper maintenance/improper refueling trigger can be used when maintenance/ground personnel do not fill the correct amount of fuel. In this scenario, low oil state will be classified as a preflight hazardous state. |
| Improper inflight planning/decision-making | |
| Improper use of procedures/directives | |
| Improper fuel consumption calculation | |
| Improper refueling | |
| Improper maintenance | |
| Improper preflight planning | |

Table 380: Triggers into the Low Oil State

| **Low Oil State** | |
|---|---|
| Hazardous state where the pilot executed an improper flare/level-off prior to landing. | |
| **Triggers into this state are** | **Notes** |
| Improper use of powerplant controls | |

| Low Oil State | |
|---|---|
| Improper inflight planning/decision-making | These triggers can cause the system to enter a low-oil state. Note that an oil system failure (e.g., oil leak) will trigger a system failure state.<br><br>The improper maintenance trigger can be used when maintenance/ground personnel do not fill the correct amount of oil. In this scenario, low oil state will be classified as a preflight hazardous state. |
| Improper use of procedures/directives | |
| Improper maintenance | |
| Improper preflight planning | |

Table 381: Triggers into the Low Hydraulic Fluid State

| Low Hydraulic Fluid State | |
|---|---|
| Hazardous state where the pilot executed an improper flare/level-off prior to landing. | |
| **Triggers into this state are** | **Notes** |
| Improper inflight planning/decision-making | These triggers can cause the system to enter a low hydraulic fluid state. Note that an oil system failure (e.g., hydraulic fluid leak) will trigger a system failure state.<br><br>The improper maintenance trigger can be used when maintenance/ground personnel do not fill the correct amount of hydraulic fluid. In this scenario, low hydraulic fluid state will be classified as a preflight hazardous state. |
| Improper maintenance | |
| Improper preflight planning | |
| Improper use of procedures/directives | |

Table 382: Triggers into the Low Coolant State

| Low Coolant State | |
|---|---|
| Hazardous state where the aircraft was operating with low coolant level. | |
| **Triggers into this state are** | **Notes** |
| Improper inflight planning/decision-making | These triggers can cause the system to enter a low coolant state.<br><br>The improper maintenance trigger can be used when maintenance/ground personnel do not fill the correct amount of coolant liquid. In this scenario, low coolant fluid state will be classified as a preflight hazardous state. |
| Improper maintenance | |
| Improper preflight planning | |
| Improper use of procedures/directives | |

Table 383: Triggers into the Low Lubricant State

| **Low Lubricant State** | |
|---|---|
| Hazardous state where the aircraft was operating with low grease/lubricant level. | |
| **Triggers into this state are** | **Notes** |
| Improper inflight planning/decision-making | These triggers can cause the system to enter a low lubricant fluid state. Note that a lubricating system failure (e.g., lubricating fluid leak) will trigger a system failure state.<br><br>The improper maintenance trigger can be used when maintenance/ground personnel do not fill/apply the correct amount of lubricant. In this scenario, low lubricant fluid state will be classified as a preflight hazardous state. |
| Improper maintenance | |
| Improper preflight planning | |
| Improper use of procedures/directives | |

Table 384: Triggers into the Improper Flare State

| **Improper Flare State** | |
|---|---|
| Hazardous state where the pilot executed an improper flare prior to landing. | |
| **Triggers into this state are** | **Notes** |
| Improper use of collective | In preparation for touchdown, pilots are instructed to flare the aircraft and “cushion” the landing.<br><br>• Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br>• No/failed remedial action after LOC can be inferred if LOC was the preceding state.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of throttle/powerplant controls | |
| Improper maneuvering | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of throttle and/or collective input | |
| Improper use collective and/or cyclic | |
| No/failed remedial action after LOC | |

Table 385: Triggers into the Hazardous Height-Velocity Regime State

| **Hazardous Height-Velocity Regime State** | |
|---|---|
| Hazardous state where the aircraft is operating in the unsafe region of the "Deadman's curve". | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power. |
| Improper use of collective | |
| Improper use of cyclic | |
| Improper use of flight controls | |
| Improper maneuvering | |
| Improper use of throttle and/or collective input | |
| Improper use collective and/or cyclic | |

Table 386: Triggers into the On-ground Poor Weather

| **On-ground Poor Weather State** | |
|---|---|
| Hazardous state where the pilot failed to maintain heading/course. | |
| **Triggers into this state are** | **Notes** |
| Improper weather evaluation | These triggers can cause the system to enter an on-ground poor weather state.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of inflight weather information | |
| Improper use of inflight weather advisories | |
| Improper inflight planning/decision-making | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |

Table 387: Triggers into the Improper Vertical Takeoff State

| **Improper Vertical Takeoff State** | |
|---|---|
| Hazardous state where the pilot did not perform a correct vertical takeoff. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power. |
| Improper use of collective | |
| Improper use of cyclic | |
| Improper maneuvering | |
| Improper inflight planning/decision-making | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |

| Improper Vertical Takeoff State | |
|---|---|
| Unnecessary action | Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of throttle and/or collective input | |
| Improper use collective and/or cyclic | |

Table 388: Triggers into the Improper Go-around State

| **Improper Go-around State** | |
|---|---|
| Hazardous state where the pilot did not perform a correct go-around. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of collective | |
| Improper use of cyclic | |
| Improper use of flight controls | |
| Improper maneuvering | |
| Improper inflight planning/decision-making | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of throttle and/or collective input | |
| Improper use collective and/or cyclic | |

Table 389: Triggers into the Exceeding Design Stress Limits State

| **Exceeding Design Stress Limits State** | |
|---|---|
| Hazardous state where aerodynamic loads on the aircraft exceed the design stress limits. | |
| **Triggers into this state are** | **Notes** |
| Improper use of collective | These triggers can put the system in a state where the aircraft exceeds its design stress limits. |
| Improper use of cyclic | |
| Improper use of flight controls | |
| Improper maneuvering | |

Table 390: Triggers into the Improper Translational Lift State

| **Improper Translational Lift State** | |
|---|---|
| Hazardous state where the aircraft did not transition correctly from hover to forward flight. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | • Improper use of throttle and/or collective input can be inferred as long as |
| Improper use of collective | |
| Improper use of cyclic | |
| Improper use of flight controls | |

| Improper Translational Lift State | |
|---|---|
| Improper inflight planning/decision-making | there was no loss of engine power.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of throttle and/or collective input | |

Table 391: Triggers into the Improper Precautionary Landing State

| **Improper Precautionary Landing State** | |
|---|---|
| Hazardous state where the pilot did not execute a proper precautionary landing. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of collective | |
| Improper use of cyclic | |
| Improper use of flight controls | |
| Improper inflight planning/decision-making | |
| Improper remedial action | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Improper use of throttle and/or collective input | |
| Improper use collective and/or cyclic | |

Table 392: Triggers into the Hazardous Powerplant Operation State

| **Hazardous Powerplant Operation State** | |
|---|---|
| Hazardous state where the aircraft powerplant parameters are in excess of the specified operational limits. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | Improper use of throttle and/or collective input can be inferred. |
| **Improper use of throttle and/or collective input** | |

Table 393: Triggers into the Near Midair Collision State

| **Near Midair Collision State** |
|---|
| Hazardous state where two or more aircraft almost collided with each other during flight. |

| Near Midair Collision State | |
|---|---|
| **Triggers into this state are** | **Notes** |
| No action after being disoriented | Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Not complying/obtaining ATC instructions | |
| Improper communication | |
| Correct traffic advisory not used/obtained | |
| Correct safety advisory not used/obtained | |
| Improper inflight planning/decision-making | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |

Table 394: Triggers into the Exceeding Helicopter Hover Performance State

| Exceeding Helicopter Hover Performance State | |
|---|---|
| Hazardous state where the aircraft exceeds its design hover performance. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of collective | |
| Improper use of cyclic | |
| Improper use of flight controls | |
| Improper inflight planning/decision-making | |
| Improper remedial action | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of throttle and/or collective input | |

Table 395: Triggers into the Exceeding Aircraft Takeoff Capability State

| Exceeding Aircraft Takeoff Performance State | |
|---|---|
| Hazardous state where the aircraft exceeds its design takeoff performance. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | These triggers can cause the system to enter a state where it is being operated beyond its takeoff capability. |
| Improper use of collective | |
| Improper use of cyclic | |
| Improper use of flight controls | |
| Improper inflight planning/decision-making | |

| Exceeding Aircraft Takeoff Performance State | |
|---|---|
| Improper remedial action | • Improper use of throttle and/or collective input can be inferred if none of the database triggers are available, and as long as there was no loss of engine power. Note that a loss of engine power can potentially occur **after** exceeding take off capability.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Improper use of throttle and/or collective input | |

Table 396: Triggers into the Exceeding Aircraft Landing Capability State

| **Exceeding Aircraft Landing Performance State** | |
|---|---|
| Hazardous state where the aircraft exceeds its design landing performance. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of collective | |
| Improper use of cyclic | |
| Improper use of flight controls | |
| Improper inflight planning/decision-making | |
| Improper remedial action | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Improper use of throttle and/or collective input | |
| Improper use collective and/or cyclic | |

Table 397: Triggers into the Improper Lift-off State

| **Improper Lift-off State** | |
|---|---|
| Hazardous state where the aircraft did not lift-off correctly. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | |
| Improper use of cyclic | |

| **Improper Lift-off State** | |
|---|---|
| Improper use of collective | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of flight controls | |
| Improper inflight planning/decision-making | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Improper use of throttle and/or collective input | |

Table 398: Triggers into the Exceeding Aircraft Performance Limits State

| **Exceeding Aircraft Performance Limits State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design performance capabilities. | |
| **Triggers into this state are** | **Notes** |
| Improper use of flight controls | These triggers can put the system in state where it is operating beyond its performance limits.<br><br>I do not use triggers relating to collective, cyclic, or throttle control as this state (which is derived from a generic NTSB) code, does not clearly indicate an aspect of performance that was exceeded (e.g., climb performance) |
| Improper inflight planning/decision-making | |
| Improper remedial action | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |

Table 399: Triggers into the Improper Operation of Rotorcraft State

| **Improper Operation of Rotorcraft State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design performance capabilities. | |
| **Triggers into this state are** | **Notes** |
| Improper use of flight controls | These triggers can put the system in state where it is not being operated properly.<br><br>I do not use triggers relating to collective, cyclic, or throttle control as this state (which is derived from a generic NTSB) code, does not clearly indicate an aspect of rotorcraft operation that was not correct. |
| Improper inflight planning/decision-making | |
| Improper remedial action | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |

Table 400: Triggers into the Exceeding Aircraft Yaw Performance State

| **Exceeding Aircraft Yaw Performance State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design yaw performance capabilities. | |
| **Triggers into this state are** | **Notes** |
| Improper use of cyclic | In order to maintain yaw performance, pilots need to use collective control or use the anti-torque pedals.<br><br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br>• No action after disoriented state can be inferred if the preceding state was "disoriented/lacking awareness".<br>• Improper use of anti-torque control can be inferred when the improper yaw performance state is preceded by LTE or exceeding crosswind component states.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use tail rotor/anti-torque control | |
| Improper compensation for winds | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Improper use of collective and/or cyclic | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of collective and/or cyclic | |
| No action after disoriented state | |
| Improper use of anti-torque control | |

Table 401: Triggers into the Exceeding Aircraft Engine-out Capability State

| **Exceeding Aircraft Engine-out Capability State** | |
|---|---|
| Hazardous state where the aircraft is operated beyond its performance capabilities after the loss of engine power. | |
| **Triggers into this state are** | **Notes** |
| Improper use of collective | These triggers can cause the system to move to state where it has exceeded its performance limits when one or more engine(s) is/are not operational.<br><br>• Improper use of collective and/or cyclic can be inferred if there was no engine power. |
| Improper use of cyclic | |
| Improper remedial action | |
| Improper use of flight controls | |
| Improper use of rotorcraft flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |

| Exceeding Aircraft Engine-out Capability State | |
|---|---|
| Unnecessary action | Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Not possible | |
| Improper use of collective and/or cyclic | |

Table 402: Triggers into the Exceeding Aircraft Crosswind Capability State

| Exceeding Aircraft Crosswind Performance State | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design crosswind performance capabilities. | |
| **Triggers into this state are** | **Notes** |
| Not identifying crosswind component | These triggers can cause the system to move into a state where it has exceeded its crosswind performance capability.<br><br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br>• No action after disoriented state can be inferred if the preceding state was "disoriented/lacking awareness".<br>• Improper use of anti-torque control can be inferred if the accident involved improper heading, LTE, or exceeding yaw performance. This trigger can be assigned to multiple states. |
| Improper use tail rotor/anti-torque control | |
| Improper compensation for winds | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Improper use of collective and/or cyclic | |
| Incomplete action | |
| Unnecessary action | |
| Not possible | |
| Improper use of collective and/or cyclic | |
| No action after disoriented state | |
| Improper use of anti-torque control | |

Table 403: Triggers into the Exceeding Aircraft Configuration Capability State

| Exceeding Aircraft Configuration Capability State | |
|---|---|
| Hazardous state where the aircraft is operated beyond its design capabilities for a given configuration. | |
| **Triggers into this state are** | **Notes** |
| Improper use of flight controls | These triggers can put the system in state where it is being operated beyond its capability for the given configuration<br><br>I do not use triggers relating to collective, cyclic, use of landing gear, or throttle control as this state (which is derived |
| Improper inflight planning/decision-making | |
| Improper remedial action | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |

| Exceeding Aircraft Configuration Capability State | |
|---|---|
| Incomplete action | from a generic NTSB) code, does not clearly indicate the configuration (e.g., gear position) |
| Unnecessary action | |

Table 404: Triggers into the Improper Power-on Landing State

| **Improper Power-on Landing State** | |
|---|---|
| Hazardous state where the pilot performs an improper landing with engine(s) operational. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power (power-on landing indicates engine was operational).<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of cyclic | |
| Improper use of collective | |
| Improper use of flight controls | |
| Improper inflight planning/decision-making | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Improper use of throttle and/or collective input | |

Table 405: Triggers into the Runway Undershoot State

| **Runway Undershoot State** | |
|---|---|
| Hazardous state where the aircraft landed short of the runway. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power<br>• Improper use of collective and/or cyclic can be inferred if the accident involved a loss of engine power.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of cyclic | |
| Improper use of collective | |
| Improper use of flight controls | |
| Improper inflight planning/decision-making | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Improper use of throttle and/or collective input | |
| Improper use of collective and/or cyclic | |

Table 406: Triggers into the Wheels-down Landing in Water State

| **Wheels-down Landing in Water State** | |
|---|---|
| Hazardous state where the aircraft landed on water with the wheels down. | |
| **Triggers into this state are** | **Notes** |
| Improper inflight planning/decision-making | These triggers can cause the system to enter a wheels-down landing in water state. |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |

Table 407: Triggers into the Wheels-up Landing State

| **Wheels-down Landing in Water State** | |
|---|---|
| Hazardous state where the aircraft landed without extending the landing gear. | |
| **Triggers into this state are** | **Notes** |
| Improper inflight planning/decision-making | These triggers can cause the system to land without extending landing gear. |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |

Table 408: Triggers into the On-ground Loss of Control State

| **On-ground Loss of Control State** | |
|---|---|
| Hazardous state where the pilot fails to maintain control of aircraft heading and attitude when on the ground. | |
| **Triggers into this state are** | **Notes** |
| Improper use of throttle/powerplant controls | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of collective | |
| Improper use of cyclic | |
| Improper use of flight controls | |
| Improper inflight planning/decision-making | |
| Improper remedial action | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Improper use of throttle and/or collective input | |

Table 409: Triggers into the Improper Level-off State

| **Improper Level-off State** | |
|---|---|
| Hazardous state where the pilot fails to bring the helicopter to a level attitude (usually in preparation for a landing). | |
| **Triggers into this state are** | **Notes** |
| Improper use of collective | • Improper use of throttle and/or collective input can be inferred as long as there was no loss of engine power.<br>• Improper use of collective and/or cyclic can be inferred if there was no engine power.<br><br>Note that some of the triggers (e.g., inflight planning/decision-making, delayed action) for this state can be applied to multiple states in the same accident. |
| Improper use of throttle/powerplant controls | |
| Improper maneuvering | |
| Improper remedial action | |
| Improper use of flight controls | |
| Incorrect action selected | |
| Incorrect action performed | |
| Incorrect sequence of actions | |
| Delayed action | |
| Lack of action | |
| Forgotten/omitted action | |
| Incomplete action | |
| Unnecessary action | |
| Improper use of throttle and/or collective input | |
| Improper use collective and/or cyclic | |

# APPENDIX E. DEFINITIONS OF INFORMATION CODES

Table 410: Information about the Objects that Aircraft Collided with in Accidents

| **Information about Terrain** | |
|---|---|
| Information about the nature of terrain that aircraft collided with during accidents. | |
| **NTSB Codes (pre-2008)** | **Notes** |
| Ground | These codes are modifiers associated with the subject code “19200: Terrain” in the pre-2008 coding system.<br><br>The NTSB used this subject code (along with modifiers) to provide additional information regarding the terrain that the aircraft clipped/collided with during flight. |
| None suitable | |
| Mountainous/hilly | |
| Rough/uneven | |
| Water | |
| Soft | |
| High vegetation | |
| Open field | |
| High obstruction(s) | |
| Snow covered | |
| Water, rough | |
| Crop | |
| Downhill | |
| Grass | |
| Rising | |
| High terrain | |
| Water, glassy | |
| Uphill | |
| Wet | |
| Dirt bank/rising embankment | |
| Runway | |
| Roadway/highway | |
| Congested/confined area | |
| Hidden obstruction(s) | |
| Ditch | |
| Rock(s)/boulder(s) | |
| Loose gravel/sandy | |
| Swampy | |
| Berm | |
| Drop-off/descending embankment | |
| Muddy | |
| Residential area | |
| Pinnacle | |
| Tree(s) | |
| Ravine | |
| Icy | |
| Loose objects | |
| Snowbank | |
| Tundra | |
| Other | |
| Cliff | |
| Large wave/swell | |
| Sand bar | |
| Water, frozen | |

| Information about Terrain | |
|---|---|
| Information about the nature of terrain that aircraft collided with during accidents. | |
| Blind/box canyon | |
| Construction area | |
| Plowed/furrowed | |
| Weak ice | |
| Not specified in NTSB manual | |
| Short runway/landing area | |
| Frozen | |
| **NTSB Codes (post-2008)** | **Notes** |
| Mountainous/hilly terrain | Accident recorded under the current system used codes in the terrain hierarchy, ranging from "03020000XX: Terrain-general" to "03021035XX: Terrain-wet/muddy" |
| Rough terrain | |
| Sloped/uneven | |
| Water | |
| High elevation | |
| Snowy/icy | |
| Wet/muddy | |

Table 411: Information about Airport Facilities

| Information about Airport Facilities | |
|---|---|
| Information about the landing area condition at airports | |
| **NTSB Codes (pre-2008)** | **Notes** |
| Inadequate | These code are modifiers associated with the subject codes ranging from "18500: Control tower" to "19028: Airport facilities—refueling truck"<br><br>The NTSB used these subject codes (along with modifiers) to provide additional information regarding the airport/landing site. |
| Unavailable | |
| Congested | |
| Snow covered | |
| Downhill | |
| Rough/uneven | |
| High terrain | |
| Rising | |
| Ground | |
| Soft | |
| Grass | |
| None suitable | |
| Runway | |
| Congested/confined area | |
| High vegetation | |
| Wet | |
| Other | |
| Loose objects | |
| Short runway/landing area | |
| Mountainous/hilly | |
| Foreign substance covered | |
| Open field | |
| High obstruction(s) | |
| Airport facility | |
| Unavailable | |
| Not specified in NTSB manual | |
| Lack of frangibility | |
| Hard/paved surface | |
| Inoperative | |

| Information about Airport Facilities | |
|---|---|
| Information about the landing area condition at airports | |
| False/incorrect indication | |
| Not maintained | |
| Exposed runway lip/edge | |
| Not operating | |
| **NTSB Codes (post-2008)** | **Notes** |
| Airport lighting | For accidents recorded under the current system, I grouped codes ranging from "03010000XX: Operating environment-general" to "03017035XX: Operating environment-airport facilities/design-runway/landing area condition" |
| Runway lighting | |
| Taxiway lighting | |
| Obstruction markings/lighting | |
| Runway markings/signage | |
| Runway/landing area condition | |
| Runway/landing area length | |
| Taxiway markings/signage | |
| Taxiway condition | |
| Airport communication | |
| Ramp facilities | |
| Emergency/fire/rescue services | |
| Fuel service/equipment | |
| Ground support/equipment | |
| Snow removal service/equipment | |
| Security | |

Table 412: Information about Phase of Flight

| Information about Phase of Flight | |
|---|---|
| Information about the landing area condition at airports | |
| **NTSB Codes (pre-2008)** | **Notes** |
| Standing—engine(s) not operating | These codes provide information about the different phases of flight in an accident.<br><br>These codes remain information codes unless they are used in the rules to define a hazardous state.<br><br>Note that in addition to the phase of flight code for "hover—out of ground effect", I included the subject code "24808: Out of ground effect" as an information code. |
| Taxi—aerial | |
| Climb | |
| Maneuvering—holding (IFR) | |
| Approach | |
| Go-around (VFR) | |
| Missed approach (IFR) | |
| Landing—aborted | |
| Maneuvering—aerial application | |
| Hover—out of ground effect | |
| Standing—idling rotors | |
| Taxi | |
| Taxi—pushback/tow | |
| Taxi—to takeoff | |
| Taxi—from landing | |
| Takeoff | |
| Takeoff—roll/run | |
| Takeoff—initial climb | |
| Takeoff—aborted | |
| Climb—to cruise | |
| Cruise | |
| Cruise—normal | |
| Descent | |
| Descent—normal | |
| Descent—emergency | |

| Information about Phase of Flight | |
|---|---|
| Information about the landing area condition at airports | |
| Approach—VFR pattern—downwind | |
| Approach—VFR pattern—turn to base | |
| Approach—VFR pattern—base leg/base to final | |
| Approach—VFR pattern—final approach | |
| Approach—Initial approach fix (IAF) to final approach fix (FAF)/outer marker (IFR) | |
| Approach—final approach fix (FAF)/outer marker to threshold (IFR) | |
| Approach—circling (IFR) | |
| Landing | |
| Landing—flare/touchdown | |
| Landing—roll | |
| Emergency landing | |
| Emergency landing after takeoff | |
| Emergency descent/landing | |
| Maneuvering | |
| Maneuvering—turn to reverse direction | |
| Maneuvering—turn to landing area (emergency) | |
| Hover | |
| Hover—in ground effect | |
| Other | |
| Unknown | |
| **NTSB Codes (post-2008)** | **Notes** |
| Standing | These codes provide information about the different phases of flight in an accident.<br><br>These codes remain information codes unless they are used in the rules to define a hazardous state. |
| Standing—engine not operational | |
| Standing—engine start-up | |
| Standing—engine operating | |
| Standing—engine shutdown | |
| Pushback/towing | |
| Pushback/tow—engine not operational | |
| Pushback/tow—engine start-up | |
| Pushback/tow—engine operational | |
| Pushback/tow—engine shutdown | |
| Taxi | |
| Taxi—to runway | |
| Taxi—into takeoff position | |
| Taxi—from runway | |
| Takeoff | |
| Takeoff—rejected takeoff | |
| Initial climb | |
| Enroute—Climb to cruise | |
| Enroute—Cruise | |
| Enroute—Change of cruise level | |
| Enroute—Descent | |
| Enroute—Holding (IFR) | |
| Maneuvering | |
| Maneuvering—Aerobatics | |
| Maneuvering—Low—alt flying | |
| Maneuvering—Hover | |
| Approach | |
| Approach—IFR Initial Approach | |
| Approach—IFR Final Approach | |
| Approach—Circling (IFR) | |

| **Information about Phase of Flight** | |
|---|---|
| Information about the landing area condition at airports | |
| Approach—IFR Missed Approach | |
| Approach—VFR Pattern Crosswind | |
| Approach—VFR Pattern Downwind | |
| Approach—VFR Pattern Base | |
| Approach—VFR Pattern Final | |
| Approach—VFR Go-Around | |
| Landing | |
| Landing—Flare/Touchdown | |
| Landing—Landing Roll | |
| Emergency descent | |
| Post-Impact | |
| After Landing | |
| Other | |
| Unknown | |

# APPENDIX F. OCCURRENCE CHAIN DATA

Table 413: Permissible Accident Codes (Pre-2008)

| Pre-2008 | Meaning |
|---|---|
| 150 | Ditching |
| 160 | Dragged wing, rotor, pod, float or tail/skid |
| 170 | Fire/explosion |
| 171 | Fire |
| 172 | Explosion |
| 180 | Forced landing |
| 190 | Gear collapsed |
| 191 | Main gear collapsed |
| 192 | Nose gear collapsed |
| 193 | Tail gear collapsed |
| 194 | Complete gear collapsed |
| 195 | Other gear collapsed |
| 198 | Gear retraction on ground |
| 200 | Hard landing |
| 220 | In flight collision with object |
| 230 | In flight collision with terrain/water |
| 231 | Wheels down landing in water |
| 232 | Wheels up landing |
| 270 | Midair collision |
| 271 | Collision between aircraft (other than midair) |
| 290 | Nose down |
| 300 | Nose over |
| 310 | On ground/water collision with object |
| 320 | On ground/water collision with terrain/water |
| 380 | Roll over |
| 400 | Undetermined |

Table 414: Permissible Accident Codes (Post-2008)

| Post-2008 | Meaning |
|---|---|
| 0 | Unknown or undetermined |
| 91 | Tailstrike |
| 92 | Hard landing |
| 94 | Landing gear collapse |
| 96 | Nose over/nose down |
| 97 | Roll over |

| Post-2008 | Meaning |
| --- | --- |
| 120 | Control flight into terrain/object |
| 160 | Explosion (non-impact) |
| 170 | Fire/smoke (post-impact) |
| 180 | Explosion (post-impact) |
| 200 | Ground collision |
| 231 | Dynamic Rollover |
| 245 | Mast bumping |
| 250 | Midair collision |
| 300 | Runway excursion |
| 441 | Ditching |
| 470 | Collision with terrain/object (non-CFIT) |
| 490 | Collision during takeoff/land |

# REFERENCES


Ariss, O. E., Xu, D., and Wong, W. E. (2011). Integrating Safety Analysis with Functional Modeling, *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans,* Vol. 41(4), pp. 610-624.

Ast, M. (2012). An Ontology for Aircraft Design. Diploma Thesis in Computer Science. The Technical University of Munich, 2012.

Atkinson, B., and Irving, P. (1995). An analysis of accidents involving UK civil registered helicopters during the period 1976-1993. CAA/913 V/14. 95, 1995.

Australian Transportation Safety Board (2004). General Aviation Fatal Accidents: How do they happen?—A review of general aviation fata; accidents 1991 to 2000. Aviation Research Paper B2004/0010, 2004.

Australian Transportation Safety Board (2011). Accidents involving pilots in Instrument Meteorological Conditions. AR-2011-060, 2011.

Aviation Safety and Security Program, "The Final Report of the Helicopter Accident Analysis Team" (2016). http://www.ihst.org/portals/54/industry_reports/HAAT-FinalReport.pdf, Accessed June 2016.

Baker, S. P., Shanahan, D. F., Haaland, W., Brady, J. E., and Li, G. (2011). Helicopter crashes related to oil and gas operations in the Gulf of Mexico. *Aviation, Space, and Environmental Medicine,* Vol. 82(9), 2011, pp. 885–889.

Bazargan, M., and Guzhva, V.S. (2007). Factors contributing to fatalities in general aviation. *World Review of Intermodal Transportation Research*, Vol. 1(2), pp. 170-181.

Bazargan, M., Kosalim, H., Williams, M., and Singh, A. (2012) Comprehensive Analysis of General Aviation Accident (Vols. 1 and 2). FAA report DOT/FAA/AR-12/2; March 2012.

Benner, L. (1975). Accident investigation: Multilinear events sequencing methods. *Journal of Safety Research*, Vol. 7(2), pp. 67–73.

Chen, C. T. (1995). Linear system theory and design. Oxford, UK: Oxford University Press; 1995.

Cohen, B., Cassell, R., and Smith, A. (1999). Development of an Aircraft Performance Risk Assessment Model. *Digital Avionics Systems Conference.* IEEE.

Conroy, C., Russel, J. C., Crouse, W. E., Bender, T. R., and Holl, J. A. (1992). Fatal Occupational Injury Related to Helicopters in the United States. *Aviation, Space and Environmental Medicine*, Vol. 63(1), 1992, pp. 67–71.

Dekker, S., 2006. The Field Guide to Understanding Human Error. Aldershot: Ashgate Publishing Limited; 2006.

DeVoogt, A. (2011). Fatalities in General Aviation: From Balloons to Helicopters. *Forensic Pathology Reviews*. Edited by E. E. Turk, Vol. 6, New York, NY, Springer Science and Business Media, pp. 169–179.

DeVoogt, A. J., Uitdewilligen, S., and Ermenko, N. (2009). Safety in high-risk helicopter operations: The role of additional crew in accident prevention. *Safety Science*, Vol. 47, 2009, pp. 717-721.

Dempsey, P. J., Lewicki, D. G., and Le, D. D. (2007). Investigation of Current Methods to Identify Helicopter Gear Health. NASA/TM—2007-214664, 2007.

Fala, N., and Marais, K. (2016). Detecting Safety Events during Approach in General Aviation Operations. *AIAA AVIATION, 16th AIAA Aviation, Technology, Integration, and Operations Conference,* AIAA Paper 2016-3914, Washington, D.C., June 2016.

Favaro', F. M., and Saleh, J. H. (2016). Toward risk assessment 2.0: Safety supervisory control and model-based hazard monitoring for risk-informed safety interventions. *Reliability Engineering and System Safety*, Vol. 152, pp. 316–330.

Federal Aviation Administration (2016a). Acronyms/Data Terminology—Glossary, Online: http://aspmhelp.faa.gov/index.php/Glossary, Accessed November 2016.

Federal Aviation Administration (2016). Rotorcraft Safety Initiative. Online: http://www.ihst.org/portals/54/Rotorcraft_Safety_Initiative_data_summary.pdf, Accessed May 2016.

Federal Aviation Administration (2015). General Aviation and Part 135 Surveys. Online: https://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2014/, Accessed July 2016.

Federal Aviation Administration (2016). Airworthiness Directives (ADs). Online: https://www.faa.gov/aircraft/air_cert/continued_operation/ad/, Accessed July 2016.

Federal Aviation Administration (2016b), Fly Safe: Prevent Loss of Control Accidents. Online: https://www.faa.gov/news/updates/?newsId=83285, Accessed November 2016.

Federal Aviation Administration (2016c). Helicopter Flying Handbook. Online: https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/helicopter_flying_handbook/, Accessed November 2016.

Federal Aviation Administration (2016d). Helicopter Flying Handbook (FAA-H-8083-21A) Addendum—Change-1. Online: https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/media/hfh_addendum.pdf, Accessed November 2016.

Federal Aviation Administration (1995). Unanticipated Right Yaw in Helicopters, FAA AC 90–95, Washington, DC, 1995.

Fogarty, G.J., Saunders, R. (2000). Developing a model to predict aircraft maintenance performance. *Proceedings of 10th international symposium on aviation psychology*, Columbus, OH, 2000.

Franza, A., and Fanjoy, R. (2012). Contributing Factors in Piper PA28 and Cirrus SR20 Aircraft Accidents. *Journal of Aviation Technology and Engineering*, Vol. 1(22), pp. 90–96.

Gavrilovski, A., Mavris, D.N. (2015). A Model-Based Approach for Event Definition in Support of Flight Data Monitoring. *41st European Rotorcraft Forum*, Munich, Germany, September 2015.

Goblet, V., Fala, N. and Marais, K. (2015). Identification of Phases of Flight in General Aviation Operations. *AIAA AVIATION, 15th AIAA Aviation, Technology, Integration, and Operations Conference*, AIAA Paper 2015-2851, Dallas, TX, June 2015.

Goldman, S. M., Fiedler, E. R., and King, R.E. (2002). "General Aviation Maintenance-Related Accidents: A Review of Ten Years of NTSB Data", DOT/FAA/AM-02/23, 2002.

Haaland, W. L., Shanahan, D. F., and Baker, S. P. (2009). "Crashes of Sightseeing Helicopter Tours in Hawaii", *Aviation, Space, and Environmental Medicine,* Vol. 80, No. 7, 2009, pp. 637–642.

Harel, D. (1987). Statecharts: A Visual Formalism for Complex Systems. *Science of Computer Programming*, Vol. 8, pp. 231–274.

Harris, F. D. (2012). Introduction to Autogyros, Helicopters, and Other V/STOL Aircraft—Volume II: Helicopters. NASA/SP–2012-215959 Vol II, Moffett Field, CA, October 2012.

Harrison, E., Jimenez, H., Mavris, D. N. (2015). Investigation and Flight Dynamic Analysis of General Aviation Safety. *AIAA AVIATION, 15th AIAA Aviation, Technology, Integration, and Operations Conference*, AIAA Paper 2015-3108, Dallas, TX, June 2015.

Hollangel, E. (1998). Cognitive Reliability and Error Analysis Method (CREAM). Oxford: Elsevier Science, 1998.

Hollnagel, E. (2004). Barriers and Accident Prevention. Hampshire: Ashgate; 2004.

Houston, S. J., Walton, R. O., and Conway, B. A. (2012). Analysis of General Aviation Instructional Loss of Control Accidents. *The Journal of Aviation/Aerospace Education and Research*, *Vol. 22, No.*1, 2012, pp. 35–49.

International Helicopter Safety Team (2011). The Top 10 Ways You Can Prevent Helicopter Accidents. *Helicopter Safety News,* Fairfax, VA, 2011.

International Civil Aviation Organization (2009). Review of the classifications definitions used for civil aviation activities. *Tenth Session of the Statistics Division*, STA/10-WP/7, Montreal, Canada, November 2009.

Jian, Y. (2011). Top-down State-based Modeling of Air Transportation System. MS Thesis. Purdue University.

Knecht, W. R., and Lenz, M. (2010). Causes of General Aviation Weather-Related, Non-Fatal Incidents: Analysis Using NASA Aviation Safety Reporting System Data. DOT/FAA/AM-10/13, 2010.

Krebs, M. B., Li, G., and Baker, S. P. (1995). Factors related to pilot survival in helicopter commuter and air taxi crashes. *Aviation, Space, and Environmental Medicine*, Vol. 66, pp. 99−103.

Landry, S. J., Lagu, A., and Kinnari, J. (2009). State-based modeling of continuous human-integrated systems: An application to air traffic separation assurance. *Reliability Engineering and System Safety*. Vol. 95, pp. 345–353.

Latorella, K.A., Prabhu, P.V. (2000). A review of human error in aviation maintenance and inspection. *International Journal of Industrial Ergonomics*, Vol. 26, 2000, pp.133–161.

Leveson, N. G. (2001). Safeware: System Safety and Computers, 1st ed., Boston: Addison Wesley; 2001.

Leveson, N. G. (2004). A New Accident Model for Engineering Safer Systems. *Safety Science*, Vol. 42, pp. 237-270.

Leveson, N. G. (2016). Rasmussen's legacy: A paradigm change in engineering for safety. *Applied Ergonomics*, in press, http://dx.doi.org/10.1016/j.apergo.2016.01.015

Li, G., Gebrekristos, H. T., and Baker, S. P. (2008). FIA Score: A Simple Risk Index for Predicting Fatality in Aviation Crashes. *The Journal of Trauma, Injury, Infection, and Critical Care*, Vol. 65 (6). 2008, 1278–1283.

Li, L., G. M., Hansman, R. J., and Palacios, R. (2011). Anomaly Detection in Onboard-Recorded Flight Data Using Cluster Analysis. *Digital Avionics Systems Conference (DASC).* 2011, Seattle, WA, pp. 4A4-1-4A4-11.

Li, L., and Hansman, R. J. (2013). Anomaly Detection in Airline Routine Operations Using Flight Recorder Data. Cambridge, MA, MIT International Center for Air Transportation (ICAT).

Luxhøj, J.T. and kauffeld, K. (2003). Evaluating the Effect of Technology Insertion into the National Airspace System. Online: http://rutgersscholar.rutgers.edu/volume05/luxhoj-kauffeld/luxhoj-kauffeld.htm; Accessed September 2016.

Majumdar, A., Mak, K., and Lettington, C. (2009). A causal factor analysis of helicopter accidents in New Zealand 1996–2005 and the United Kingdom 1986–2005. *The Aeronautical Journal*, Vol. 113, No. 1148, 2009, pp. 647–660.

Manwaring, J. C., Conway, G. A., and Garrett, L. C. (1998). Epidemiology and Prevention of Helicopter External Load Accidents. *Journal of Safety Research*, Vol. 29(2), pp. 107-121.

Marais, K. B., and Robichaud, M. R. (2012). Analysis of trends in aviation maintenance risk: An empirical approach. *Reliability Engineering and System Safety*, Vol. 106, 2012, pp. 104–118.

Masson, M., Van Hijum, V., and Evans, A. (2009). Human factors in helicopter accidents: results from the analysis performed by the European Helicopter Safety Analysis Team within the IHST. *AHS 65th Annual Forum and Technology Display*, Grapevine, TX, 2009.

National Transportation Safety Board (2014). NTSB Most Wanted List. Online: http://www.ntsb.gov/safety/mwl/Pages/mwl1_2014.aspx, Accessed July 2016.

National Transportation Safety Board (2015). NTSB Most Wanted List. Online: http://www.ntsb.gov/safety/mwl/Pages/mwl3_2015.aspx, Accessed July 2016.

National Transportation Safety Board (2016). Aviation Accident Database & Synopses. Online: http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx, Accessed July 2016.

National Transportation Safety Board (1998). Aviation Coding Manual. Washington DC, National Transportation Safety Board, 1998.

National Transportation Safety Board (2016). 830.2 Definitions. Online: http://www.ecfr.gov/cgi-bin/text-idx?SID=36418957aeb9385b90ae9a44f4a8d1cd&mc=true&node=pt49.7.830&rgn=div5 - se49.7.830_15, Accessed July 2016.

National Transportation Safety Board (1995). Safety Recommendation in response to A–95–1 to –8. Washington, DC, 1995.

National Transportation Safety Board (1995). Robinson Helicopter Company R22 Loss of Main Rotor Control Accidents. NTSB/SIR-96/03, Washington, DC, 1996.

National Transportation Safety Board (2014). Helicopter Safety Starts in the Hangar. *NTSB Safety Alert*, SA-032, 2014.

National Transportation Safety Board (2015). Pilots: Perform Advanced Preflight after Maintenance. *NTSB Safety Alert*, SA-041, 2015.

O'Hare, D. (2006). Cognitive functions and performance shaping factors in aviation accidents and incidents. *The International Journal of Aviation Psychology*, Vol. 16(2), pp. 145–156.

Ortmeier, F. and Reif, W. (2005). "Formal safety analysis of transportation control systems," in Proc. TRAIN@SEFM Workshop, 2005.

Patnakar, M. S., and Taylor, J. C. (2004). Applied Human Factors in Aviation Maintenance. Burlington: Ashgate Publishing; 2004.

Perrow, C. (1984). Normal Accidents: Living with High-Risk Technologies. New York: Basic Books; 1984.

Puranik, T., Harrison, E., Min, S., Jimenez, H., and Mavris, D. N. (2016a). General Aviation Approach and Landing Analysis using Flight Data Records. *AIAA AVIATION, 16th Aviation Technology, Integration, and Operations Conference*, American Institute of Aeronautics and Astronautics, AIAA Paper 2016-3913, Washington, D. C., June 2016.

Puranik, T., Harrison, E., Min, S., Jimenez, H., and Mavris, D. N. (2016b). Energy Based Metrics for General Aviation Flight Data Record Analysis. *AIAA AVIATION, 16th Aviation Technology, Integration, and Operations Conference*, American Institute of Aeronautics and Astronautics, AIAA Paper 2016-3915, Washington, D. C., June 2016.

Qureshi, Z. H. (2007). A Review of Accident Modelling Approaches for Complex Socio-Technical Systems. *12th Australian Workshop on Safety Related Programmable Systems (SCS'07)*. Adelaide, Australia.

Rao, A. H., and Marais, K. (2015). Identifying High-Risk Occurrence Chains in Helicopter Operations from Accident Data. *AIAA AVIATION, 15th AIAA Aviation, Technology, Integration, and Operations Conference*, AIAA Paper 2015-2848, Dallas, TX, June 2015.

Rao, A. H., Fala, N., and Marais, K. (2016). Analysis of Helicopter Maintenance Risk from Accident Data. *AIAA SciTech, AIAA InfoTech @ Aerospace*, AIAA Paper 2016-2135, San Diego, CA, January 2016.

Rao, A. H. and Marais, K. (2016). Comparing Hazardous States and Trigger Events in Fatal and Non-Fatal Helicopter Accidents. *AIAA AVIATION, 16th AIAA Aviation Technology, Integration, and Operations Conference*, AIAA Paper 2016-3916, Washington, D. C., June 2016.

Rasmussen, J. (1997). Risk management in a 2 dynamic society: A modelling problem. *Safety Science*, Vol. 27(2/3), pp. 183–213.

Rashid, H. S. J., Place, C. S., and Braithwaite, G. R. (2010). Helicopter maintenance error analysis: Beyond the third order of the HFACS-ME. *International Journal of Industrial Ergonomics,* Vol. 40, pp. 636–647.

Reason, J. (1990). Human Error. New York: Cambridge University Press; 1990.

Reason, J. (1997). Managing the Risk of Organizational Accidents. Surrey, UK: Ashgate Publishing; 1997

Reif, W., Schellhorn, G., and Thums, A. (2000). Safety analysis of a radio-based crossing control system using formal methods. 9th IFAC Symposium on Control in Transportation Systems, 2000, pp. 289–294.

Saleh, J. H., Slatmarsh, E. A., Favaro', F. M., and Brevault, L. (2013). Accident precursors, near misses, and warning signs: Critical review and formal definitions within the framework of Discrete Event Systems. *Reliability Engineering and System Safety*. Vol. 148, pp. 148–154.

Shappel, S. A. and Wiegmann, D. A. (2000). The Human Factors Analysis and Classification System (HFACS). Federal Aviation Administration, Office of Aviation Medicine, Report No. DOT/FAA/AM-00/7, Office of Aerospace Medicine, Washington, DC.

Shappel, S. A. and Weigmann, D. A. (2001). Applying Reason: the human factors analysis and classification system (HFACS). *Human Factors and Aerospace Safety,* Vol. 1, pp. 59–86.

Shappell, S. A., and Wiegmann, D. A. (2003). A human error approach to aviation accident analysis: The human factors analysis and classification system. Burlington: Ashgate Publishing, Ltd., 2003.

Shetty, K. I. and Hansman, R. J. (2012). Current and Historical Trends in General Aviation in the United States. ICAT-2012-6, Cambridge, MA, August 2012.

Shorrock, S., Young, M., Faulkner, J. (2003). Who moved my (Swiss) cheese? *Aircraft and Aerospace*, pp. 31–33.

Smith, A., Rick Cassell, Y. E., Sleep, B., and Cohen, B. (2000). Feasibility Demonstration of an Aircraft Performance Risk Assessment Model. Philadelphia, PA: IEEE.

Sorenson, D. and Marais, K. (2016). Patterns of Causation in Accidents and Other Systems Engineering Failures. *IEEE Systems Conference*, April 2016, IEEE, Orlando, FL.

Tsagkas, V., Nathanael, D., and Maramaras, N. (2014). A pragmatic mapping of factors behind deviating acts in aircraft maintenance. *Reliability Engineering and System Safety*, Vol. 130, 2014, pp. 106–114.

Underwood, P., and Waterson, P. (2014). Systems thinking, the Swiss Cheese Model and accident analysis: A comparative systemic analysis of the Grayrigg train derailment using the ATSB, AcciMap and STAMP models. *Accident Analysis and Prevention*. Vol. 68, pp, 75–94.

United States Joint Helicopter Safety and Analysis Team, (2011). *The Compendium Report: The US JHSAT Baseline of Helicopter Analysis.* Fairfax, VA: International Helicopter Safety Team.

Vesely W, Stamatelatos M, Dugan J, Fragola J, Minarick J, Railsback J. (2002). Fault tree handbook with aerospace applications. Washington, DC: NASA Office of Safety and Mission Assurance; 2002.

Young, M., Shorrock, J., Faulkner, J., and Braithwaite, G. (2004). Who moved my (Swiss) cheese? The (r)evolution of human factors in transport safety investigation. *International Society of Air Safety Investigators (ISASI) 2004 Proceedings*. Gold Coast, Queensland, Australia.

# VITA

Arjun Rao is from the city of Bangalore, India. Here, he completed his high-school education in May 2005. In 2009, he received his Bachelor of Engineering degree in mechanical engineering from the R.V. College of Engineering, Bangalore.

Then, he moved to the US to enroll at the University of Illinois at Urbana-Champaign for his Master's degree. During his time at Illinois, he researched low speed aerodynamic flight of RC-scale (remote-controlled) aircraft under the guidance of Prof. Michael S. Selig. He received his Master of Science degree in aerospace engineering in May 2012.

Following his MS, Arjun moved to Purdue University and joined the Value through Reliability, Safety, and Sustainability (VRSS) research group, under the guidance of Prof. Karen Marais. Here, he was given the license to research a variety of topics including aviation safety, complex systems safety, and accident modeling. He was also given the opportunity to serve as a teaching assistant (and substitute lecturer) under the stewardship of his advisor.